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UNDERSTANDING CLIMATE CHANGE

INTRODUCTION

In the last decade or so, interest in the phenomena referred to as "Climate Change" has exploded. The media and various NGOs are being joined by politicians who are all touting the messages that "this is a recent development, it is catastrophic, and it is caused by the activities of mankind". At times, the messaging is shrill and hysterical. A sober, educated look at the scientific facts and the historical climate records is called for, and that is the purpose of this document.

There is no doubt that the climate **is** changing, just like it always has, and always will. We need to know how the climate has changed in the past, what causes the changes, what is likely to happen in the future, and what (if anything) man can (or should) do to affect this.

CLIMATE VERSUS WEATHER

When a person speaks about "weather", they are referring to how the atmosphere is behaving over the short term (hours or days), and usually about how it directly affects them (in terms of temperature, precipitation, humidity, wind, etc.). The term "climate" refers to the statistics of weather over a defined large region over a long period of time (decades or more). The difference between Climate and Weather is primarily a matter of time and area.

The words "climate" and "weather" refer to temperature, precipitation, humidity, and similar terms that describe the state of the atmosphere. This document will frequently use the term "climate change", but it is primarily addressing "global temperature change."

TEMPERATURE AND ITS MEASUREMENT

All the discussion and concern about climate change seems to focus on one aspect of climate - *temperature.*

Temperature is a measure of how hot or cold something is, and it is measured with a thermometer. Most of the world uses the Celsius system of specifying temperature, where zero degrees is the temperature at which fresh water freezes, and 100 degrees C is the temperature at which fresh water boils at sea level. The scientific world often specifies temperature in terms of degrees Kelvin (K), where zero degrees is referred to as Absolute Zero, and is the coldest temperature possible, at which all molecules and atoms become motionless. A temperature expressed in degrees Kelvin can be converted to Celsius by subtracting 273.

Discussions of climate change focus on what is commonly referred to as the "Global Temperature", which is supposed to be the average temperature of the Earth. This temperature is intended to represent that of the atmosphere that is close to the earth's surface (at an altitude of 1.5 metres). There are actually a number of problems in coming up with a meaningful number for an average temperature for the Earth, and these were thoroughly outlined in a 2006 paper by Essex, McKitrick, and Andresen entitled "Does A Global Temperature Exist?" [1]. Most climate change papers ignore or downplay the issues raised in this paper as the studies then present inferred historical temperatures, extract trends, postulate causes, and try to project the future. When published, this paper was controversial, as it cast doubt on the conclusions reached by many climate researchers, and it is now difficult to obtain a copy from freely available publication sources.

Reliable equipment for measuring temperature has been available since the early 1800's, and distributed networks of these devices have been used to record historical temperatures that are used in the study of Climate Change. Unfortunately, the number and placement of temperature recording stations has changed considerably over time, so it is often difficult to get a complete and consistent record for a specific area.

Temperature history for the period preceding the nineteenth century must be inferred by analyzing ice cores, tree growth rings, sediments, and corals. Ice cores (typically from Greenland, Antarctica, or the Arctic) are the most commonly-used "proxies", and it is possible to infer temperatures from thousands of years ago. It is also possible to estimate the historical composition of the atmosphere using ice cores, but diffusion effects may mask some of the inferred extremes (of both composition and temperature)

Cores taken from the bottom of oceans and lakes will often yield stratified sediment samples that can then be subjected to isotope analysis to determine the approximate age and certain atmospheric characteristics (including temperature and CO_2 concentration) at the time of deposition.

Although surface temperature is what humans actually "feel" on a day-to-day basis, that data can be contaminated by the "urban heat islands" that are caused by construction of roads, parking lots, and structures that change the localized reflectivity and thermal mass of the surface. Because of this, it is sometimes more meaningful to talk about the temperature of the troposphere, which is the lowest layer of the Earth's atmosphere (about 20 Km thick), and is where all weather takes place (clouds, precipitation, storms, winds). Temperatures in the troposphere can be directly measured by balloon-borne radiosondes, or inferred from satellite radiometry.

EARTH'S HISTORICAL TEMPERATURE RECORD

"**Paleoclimatology**" is the study of the earth's climate over the history of the planet's existence. The earth is approximately 4.5 billion years old, and a variety of proxies must be used to infer the climate over most of this period. For convenience, the 4.5 billion year history (referred to as the "Geological Time Scale") is divided (primarily on the basis of where rocks, fossils, and fauna were found, or major geological events are believed to have occured) into various categories defined as: Eons, Eras, Periods, and Epochs. Figure 1 is a graphic representation of the categories in the Geological Time Scale. Note that the top of the chart represents the present time:

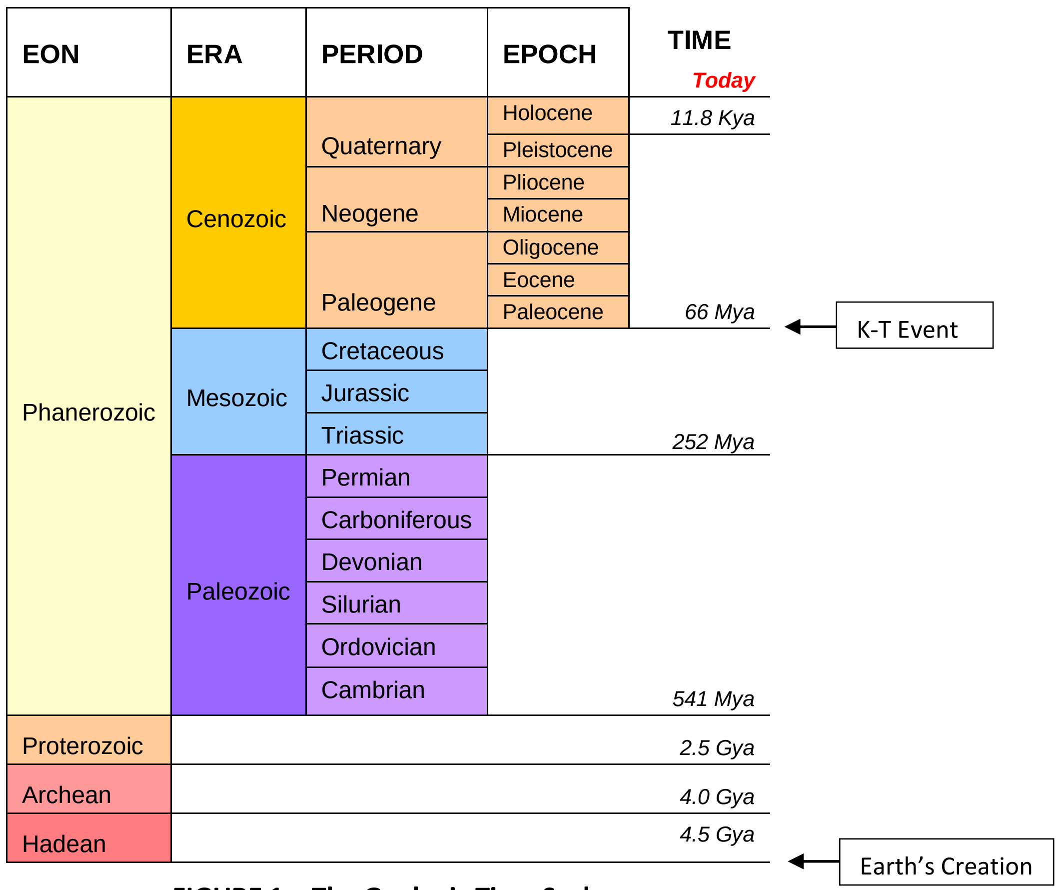


FIGURE 1 – The Geologic Time Scale

Note that the relative sizes of the cells in the above graphic are not to scale! The date scale is also <u>highly</u> non-linear.

Time abbreviations are:

> **Kya** = Thousand year ago
> **Mya** = Million years ago
> **Gya** = Billion years ago

NOTE - These time abbreviations will now be used throughout the rest of this document.

The earliest forms of life (bacteria and algae) appeared approximately 3.5 Gya. The first appearance of Modern Man (Homo Sapiens) was about 200 Kya. Archaeological research shows that a predecessor (Homo Erectus) first used tools about 2 Mya.

Looking at Figure 1, note the boundary between the Mesozoic Era and the Cenozoic Era, which occurred about 66 Mya. Just prior to this time boundary, dinosaurs were quite common, but it is believed that a massive asteroid hit the earth 66 Mya, and devastated the global environment, causing the mass extinction of three quarters of the plant and animal species on Earth, including the dinosaurs. This is known as the K-Pg extinction event, or "K-T Event".

Reliable historical temperature information from the period before the K-T Event is difficult to obtain, but the period afterwards (the last 66 million years) can be estimated using a variety of proxies.

A compressed graphic of the earth's temperature record since the K-T Event is shown in Figure 2, which uses a variety of proxy data to produce a continuous record:

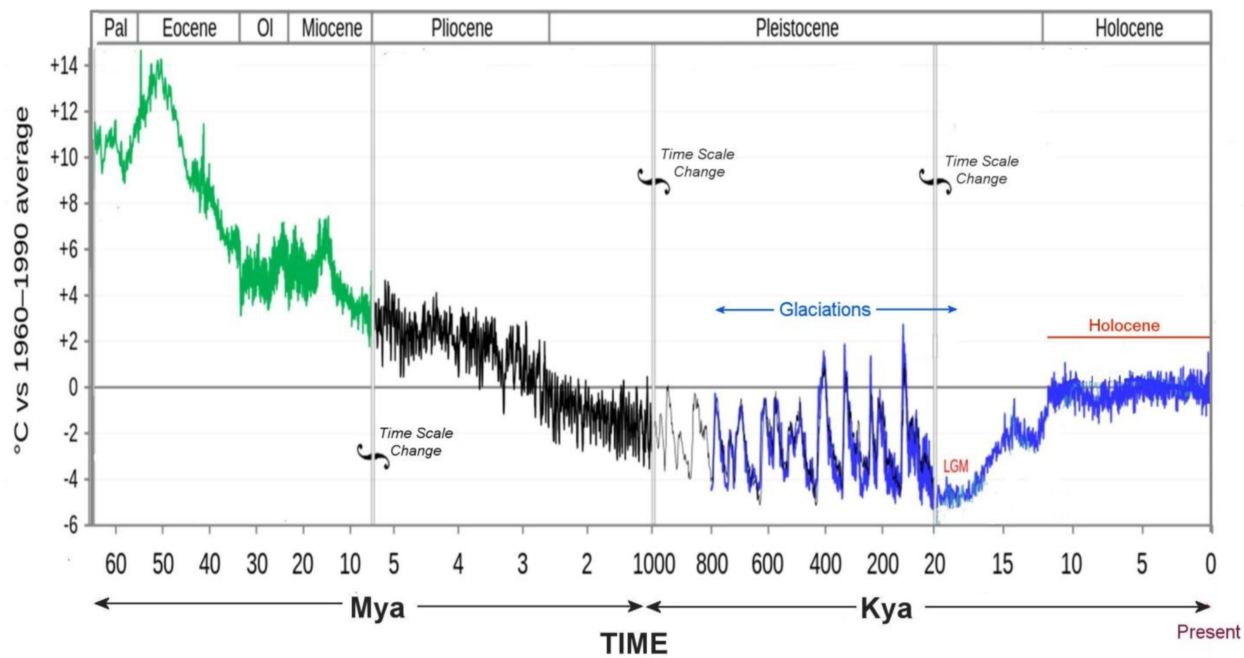


FIGURE 2 – Compressed, non-linear record of the Earth's average temperature since the K-T Event.

(This chart was created by simplifying the image available at: https://commons.wikimedia.org/wiki/File:All_palaeotemps.png)

Note that there are several scale changes on the horizontal axis ("Time"), and it is plotted logarithmically, which greatly expands the more recent times. The "LGM" note shows the time of the "Last Glacial Maximum", when glaciers covered more than 8% of the earth's surface, and the sea level was about 400 feet lower than today. Note that the region marked as "Holocene" represents the last 11.8 Kya where the temperature has been relatively steady. From about 12 Kya to about 800 Kya, the temperature oscillates as the Earth experiences a series of glaciations.

Figure 2 illustrates that the relatively stable temperature experienced during the recent Holocene is an anomaly, and the normal condition has a much "noisier" temperature record. Of course, the horizontal scale changes distort the picture somewhat. Chart 3 plots just the last 800,000 years, using a linear time scale:

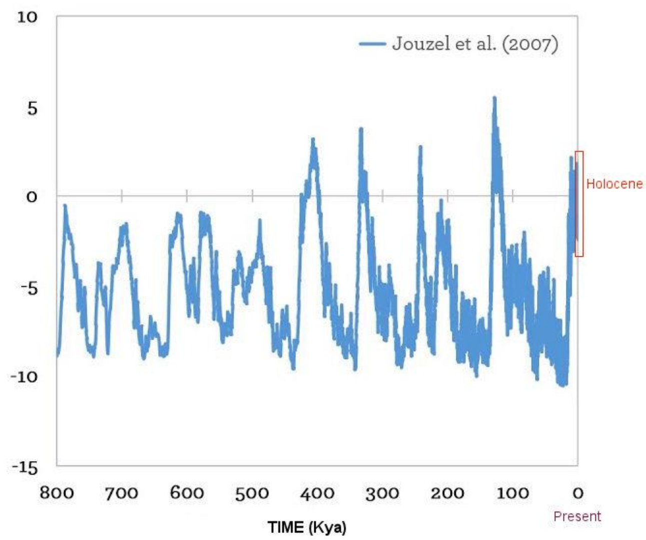


FIGURE 3 – 800,000 year temperature record, showing the cyclic glacial periods.

The area within the narrow red box is the Holocene, which is expanded below.

This chart is based on analysis of ice cores taken in the Antarctic. Of course, this is not the actual Earth's global temperature, but it is indicative of it. What is plotted is the temperature variation from the average temperature over the past 1,000 years. The glacial cycles are clearly shown, and the entire Holocene period (inside the red box) is shown as a relatively short period at the extreme right side of graph. Looking at this graphic, a casual observer would probably conclude that: **a)** getting alarmed about temperature trends over the past decade or century seems unsupportable, and **b)** we appear to be in an interglacial period, and should possibly start thinking about a new ice age in a few thousand years.

Let's now expand the time scale still further. Figure 4 looks at the temperature record of just the Holocene period (the region shown inside the red box in the graphic above):

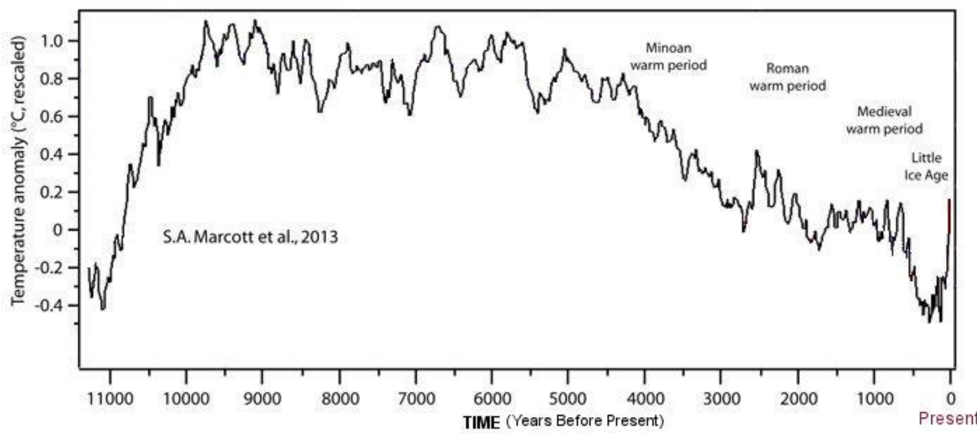


FIGURE 4 – Average global temperature during the Holocene (the past 11,700 years)

Looking at graphs 2 through 4, we can conclude that, since the K-T event, the global temperature has been slowly declining, with cyclic variations in the past 800,000 years that have resulted in a series of glaciations. We are currently between glaciations, enjoying a relatively constant temperature, with minor perturbations.

EARTH'S SOURCES OF HEAT

Heat is just a form of energy, and it is commonly measured in units of Joules. It exists as a property that is contained within a material (solid, liquid, or gas), and can be thought of as the kinetic energy of the movement of the material's molecules and atoms. The term "temperature" relates to the amount of heat in an object.

Heat always flows from a hotter object to a cooler object. The rate of heat transfer is measured in Watts, which are defined as "Joules per Second".

The earth has its own internal heat sources, such as its radioactive core, but these are very small. The earth's temperature is primarily a function of the electromagnetic energy received from the sun (so-called "solar radiation"). In the absence of the sun or any internal heat sources, the earth's temperature would be close to absolute zero, which is -273°C, or 0°K.

The sun is the primary source of energy for the earth. It is a so-called "black body radiator", and a broad spectrum of electromagnetic wavelengths is emitted, but the peak wavelength is at about 502 nm, which corresponds to green-blue light. This peak wavelength is a function of the temperature of the sun's surface. The total amount of energy emitted by the sun across all wavelengths varies as the fourth power of the sun's surface temperature. The sun's surface temperature is 5,772 degrees K and the total energy radiated in all directions is 3.8×10^{26} Watts.

As a spherical black body radiator, the sun emits its solar radiation uniformly in all directions. The power density observed at distances far from the sun's surface can easily be calculated using geometry.

The distance from the Earth to the Sun varies during a calendar year, but today has an average of 147 million Km. The black body radiation originating from the sun (across all wavelengths) therefore has an average illuminating power density of approximately 1367 Watts/m^2 at the top of the earth's atmosphere.

Using basic geometry, it can easily be shown that (ignoring all atmospheric effects), this is equivalent to a perpendicular average flux across the entire surface of the Earth of 341.2 Watts/m^2.

Looking at just the major factors, The amount of solar energy being absorbed by the Earth's surface is dependent on four parameters:

1. The energy being emitted by the sun. (both the total amount, and its spectral distribution)
2. The distance between the sun and the earth. (this affects the received energy in an inverse square law relationship)
3. Influences of the earth's atmosphere. (shading, reflection, absorption, radiation, etc.)
4. Characteristics of the surface of the earth (such as its reflectivity at various wavelengths) that determine how much total solar energy is absorbed, and how much is reflected. The term "Albedo" is used to quantify this characteristic: albedo is defined as the ratio of solar irradiance that is diffusely reflected by a surface to the irradiance received by that surface. [2]

The energy emitted by the sun has been changing over time. It is believed that about 3 or 4 Gya, the sun's output was about 70% of today's values, but that it has been relatively constant during the Holocene. Some studies have shown a small cyclic variation with a period of 1500 years.

Darker, cooler areas (at about 3,800° K) on the surface of the Sun (so-called "sun spots") vary over an 11 year cycle. The magnitude of these spots also varies over a much longer cycle that is suspected might be caused by "tides" on the sun's surface due to gravitational effects from the orbits of Jupiter, Saturn, Earth, Mercury, and Uranus. Continuing analysis of this has added credibility to this theory.[3] Other theories based on relativistic causes or inter-planetary electric fields have also been proposed. Here is a historical record of observed sunspot numbers over the past 400 years:

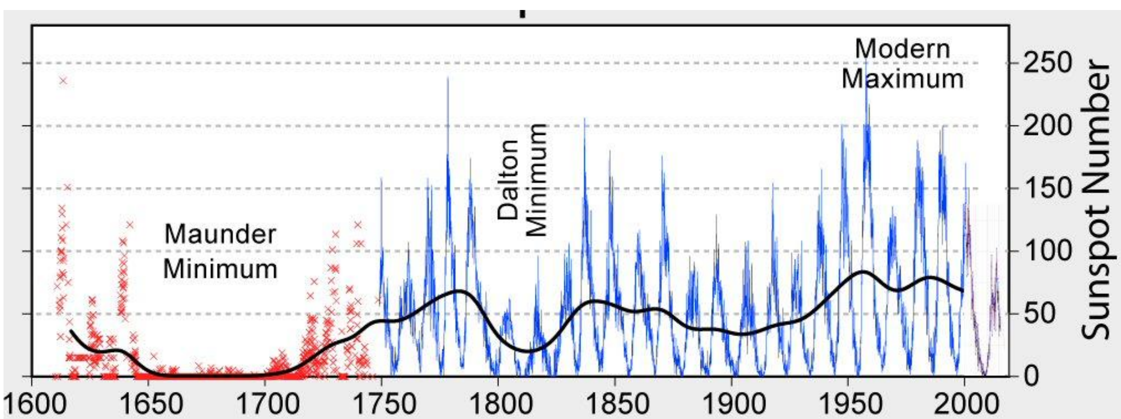


FIGURE 5 – Sunspots over the past 400 years

The net effect of these cycles is to change the outgoing radiation from the sun that eventually strikes the Earth's atmosphere.

These cycles also have a major effect (by at least a magnitude factor of 10) in radiation of extreme ultraviolet (EUV), which can strongly affect the chemistry and thermal characteristics of the earth's upper atmosphere.[4] Ultraviolet radiation from the sun affects the formation of ozone and clouds.

Here is a closer look at the last 5 sunspot cycles. Cycle 25 is expected to peak in the summer of 2025.

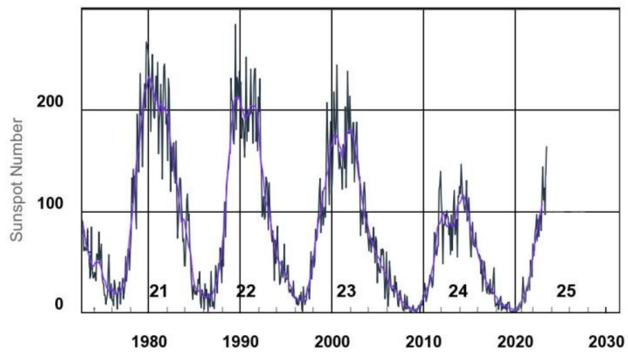


FIGURE 6 – Recent sunspot cycles.

The 11 year sunspot cycles strongly affect the state of ionization of the ionosphere, and therefore have a major effect on the highest radio frequency that can be used to cover long distances (using "skip") in the shortwave radio bands.

The amount of incoming solar energy that actually reaches the earth's surface is affected by many atmospheric variables: clouds, scattering, absorption, water vapour, etc.

If it were not for the atmosphere, the earth would be a much colder place. Energy received from the sun would heat the earth's surface, but "black body radiation" from the earth's surface would radiate much of this energy into space. An equilibrium average global temperature of approximately -18°C would result in the amount of radiating energy being equal to the absorbed solar energy. The atmosphere stops a significant portion of this heat loss by acting as a "greenhouse", thereby warming the earth to comfortable temperatures. We will now discuss how the atmosphere functions as a "greenhouse".

THE GREENHOUSE EFFECT

The sun emits energy in the form of electromagnetic radiation (EM radiation). In order to understand the greenhouse effect, we will first review this type of radiation. Depending on its wavelength, EM radiation can represent radio waves, visible light, ultraviolet (UV) light, infrared (IR) radiation, X-rays, etc. The following spectrum chart illustrates this:

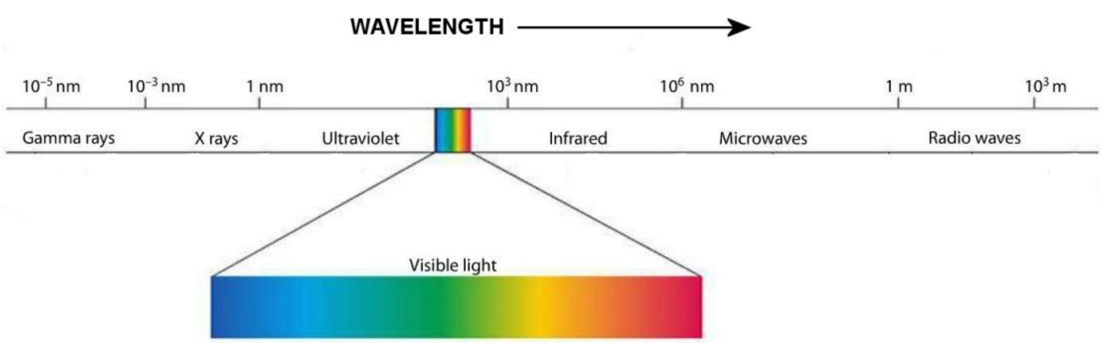
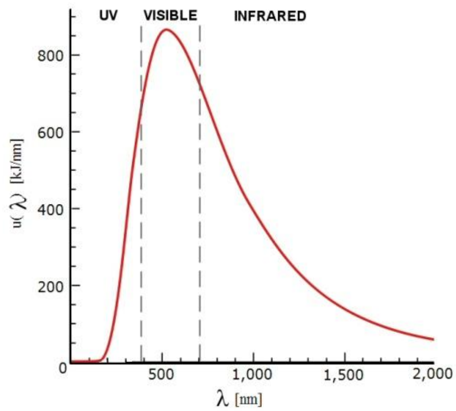


FIGURE 7 – The electromagnetic spectrum

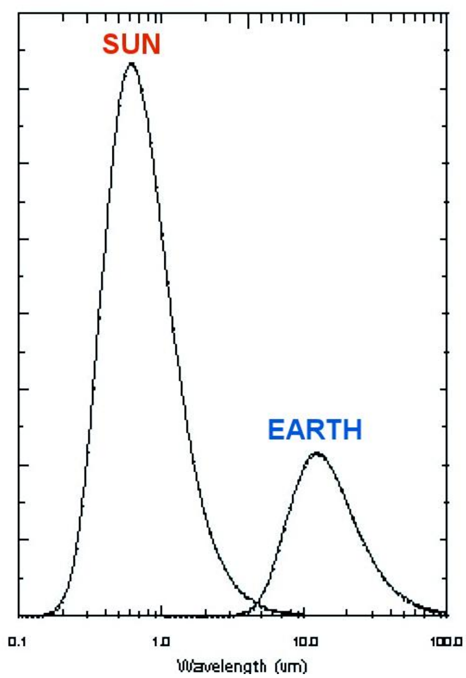
The sun does not emit a single wavelength: it is a so-called "black body emitter", and as such, emits a range of different wavelengths of EM radiation based on its surface temperature (5,772°K). Solar energy is distributed across this series of wavelengths (λ) as shown below:



The sun's EM radiation is distributed into three broad ranges: 7% in the UV portion of the spectrum, 44% in the visible spectrum, and 48% in the infrared region.

FIGURE 8 – Spectral distribution of the sun's electromagnetic radiation

The earth itself also acts as a "black body emitter". Its average surface temperature is about 287°K, and its emitted spectrum is therefore centred in the IR range, as shown below:



This diagram plots the relative intensity of the black body radiation from the sun and the earth as a function of wavelength.

Black body radiation consists of a continuous spectrum of emitted wavelengths. The peak radiation is at a wavelength that is inversely proportional to surface temperature, and the total emitted energy varies as the fourth power of the surface temperature. These relationships are defined by the Stefan-Boltzman Law [5], Planck's Law [6], and Wein's Displacement Law.[7]

FIGURE 8 – Black body radiation from the sun and earth

Look for the moment at EM energy that travels from the sun to the surface of the earth. A portion of the energy is re-radiated by the earth's surface, and it has to pass through the atmosphere on <u>both</u> trips. The atmosphere's gases have an effect on the energy: the dominant factor is absorption, which is often a function of wavelength. The amount of absorption varies with the concentration of the gas in accordance with the Beers-Lambert Law.[8] The greenhouse effect is caused by the fact that water vapour and other so-called "greenhouse gases" exhibit differing absorption and reflectivity characteristics between the shorter-wavelength incoming solar EM energy (centred at about 500 nm, as shown in the preceding diagrams) and the longer-wavelength IR energy (in the range of 10μm) that is emitted by the earth's surface. Some of the outbound IR energy from the earth's surface is absorbed by the greenhouse gases, causing heating, and this in turn sets up its own black body radiation both toward the earth and into space, as well as heating air in the lower troposphere. The net effect is that energy is "trapped" in the lower levels of the atmosphere, and as a result the earth's surface is much warmer than it would be in the absence of these greenhouse gases. Note that it is believed there are "escape holes" in the two polar regions (roughly coincident with the ozone holes) that potentially allow trapped heat energy to escape from the earth: more research is needed in this field.

Also note that the greenhouse effect is <u>not linearly proportional</u> to the concentration of the greenhouse gases: it varies with the <u>logarithm</u> of the concentration.[9] The temperature increase contribution caused by a rise of CO_2 concentration from 400 to 500 ppmv (parts per million by volume) is much less than that caused by a rise from 200 to 300 ppmv. This fact is seldom mentioned in popular literature which discusses the possible climactic danger of increasing CO_2 levels [10].

GREENHOUSE GASES

There are many different greenhouse gases. Major components of the atmosphere by volume are listed below:

Nitrogen	78% or 780,000 parts per million by volume (ppmv)	
Oxygen	21% or 210,000 ppmv	
Argon	1% or 10,000 ppmv	
Water Vapour	0.001% to 5% or 10 to 50,000 ppmv	(*A Greenhouse Gas*)
Carbon Dioxide	410 ppmv	(*A Greenhouse Gas*)
Neon	18 ppmv	
Helium	5 ppmv	
Methane	2 ppmv	(*A Greenhouse Gas*)

Looking at the above list, Water Vapour (H_2O), Carbon Dioxide (CO_2), and Methane (CH_4) are all "greenhouse gases". Water vapour is not visible to the human eye, but when this vapour condenses to form small water droplets, the resulting clouds or fog are easily seen. Water vapour is the dominant greenhouse gas, but CO_2 receives most of the publicity!

Water Vapour is the primary Greenhouse gas, representing up to 100 times the concentration of CO_2 in the atmosphere. The atmosphere's water vapour is primarily the result of evaporation of the earth's lakes and oceans. As the Earth's temperature rises, more evaporation will occur, increasing the level of atmospheric water vapour, thereby increasing its Greenhouse Effect, and therefore causing more warming. This "positive feedback" tends to increase the effect of other external factors that affect Global Temperature. Offsetting this, there is a "negative feedback" mechanism, whereby higher levels of water vapour result in more clouds which reflect incoming solar energy back into space. Other greenhouse gases include Nitrous Oxide (N_2O), and Ozone.

In order to understand and quantify the effect of the various greenhouse gases, we need to look at their absorption spectra, which show how the absorption of each gas varies as a function of the wavelength. Figure 9 has three “panels”, with a common horizontal axis representing the wavelength.

Figure 9C is a chart showing the individual absorption spectra for Water Vapour (H_2O), Carbon Dioxide (CO_2), Oxygen and Ozone (O_2 and O_3), Methane (CH_4), and Nitrous Oxide (N_2O). It also shows the spectral absorption due to Rayleigh Scattering, which is the scattering of shorter wavelengths of light on individual air molecules, giving the sky its characteristic blue colour. All of these absorption spectra block specific wavelength bands, and the composite (shown in grey in Figure 9B) represents the total attenuation of electromagnetic energy passing through the atmosphere due to both absorption and scattering. The composite is the <u>sum</u> of the individual absorption and scattering spectra.

If you look at Figure 9A, you will see the spectrum of the incoming solar energy in red. The continuous red curve shows the spectral intensity of the incoming solar radiation before it passes through the atmosphere, and the somewhat ragged red area below the curve represents the spectral intensity of the radiation that makes it all the way through the atmosphere, hitting the Earth’s surface.

Figure 9A also shows a purple continuous line that represents the spectrum of the outgoing black body radiation from the earth’s surface. The shape and position of this curve will vary somewhat, depending on the temperature of the surface. The ragged purple area below the curve shows the spectral intensity of the outgoing radiation by the time it reaches the top of the atmosphere.

Both the smooth red curve and smooth purple curve are drawn as having the same peak height, but this is for illustrative purposes only. The magnitude of the red curve (the incoming solar flux) is actually much higher than the purple curve (the outgoing energy), as illustrated previously in Figure 8.

In looking at Figure 9C, it can be seen that the absorption peak of CO_2 in the region of 14 microns is largely “blanketed” by the absorption from water vapour.

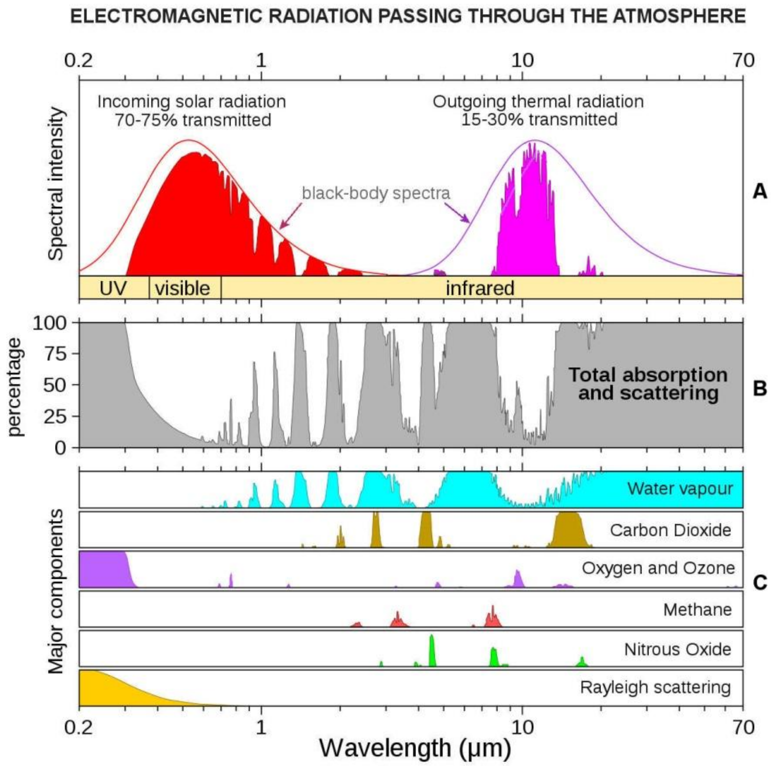


FIGURE 9 – Effect of spectral absorption of electromagnetic radiation passing through the atmosphere. Panel B shows the total absorption and scattering of EM energy passing through the atmosphere as a function of wavelength. It is the sum of the spectral components in panel C.

The incoming energy density (measured in Watts per square metre) at the surface of the Earth is proportional to the total area of the ragged red area in the top panel. The energy density (in Watts/m^2) transmitted into space by the Earth’s black body radiation is equal to the area of the ragged purple area in the top panel. The energy that is absorbed by the atmosphere causes heating of the gas molecules, so they in turn will have their own black body radiation whose spectrum and intensity will be a function of the temperature. In looking at the overall atmosphere, it can be seen that there will be many paths for energy to flow, and the best way to analyze this will be to divide the atmosphere into layers, and do radiative calculations on each. This is obviously going to get very complex, as the pressure and temperature will vary between each layer. There is a sophisticated computer program known as “Hitran” that can be used to do these calculations, and a simpler, easy-to-use spin-off called “Modtran” that is freely available on the University of Chicago web site.

Modtran allows the user to specify a locality on the Earth (tropical, mid-latitude, subarctic, etc), the season, local conditions (clear sky, clouds, precipitation, etc), and set concentrations of various gases (CO_2, CH_4, Water Vapour, Ozone, and Freon). The user specifies whether the analysis should be done for energy going up or going down, and what the virtual observer’s altitude is in Km. The program then calculates and plots the energy flux in W/m^2 as a function of wavelength. The total energy flux is the area under the displayed curve. Note that the default wavelength display along the horizontal axis is in “wavenumber” units, as this is commonly used by scientists for spectrometry work. A wavenumber is the reciprocal of wavelength, and is equal to the number or complete cycles of a waveform per cm. For comparison purposes, Figure 10 displays two output displays from Modtran of the same atmospheric conditions, one using wavenumbers, and one using wavelengths:

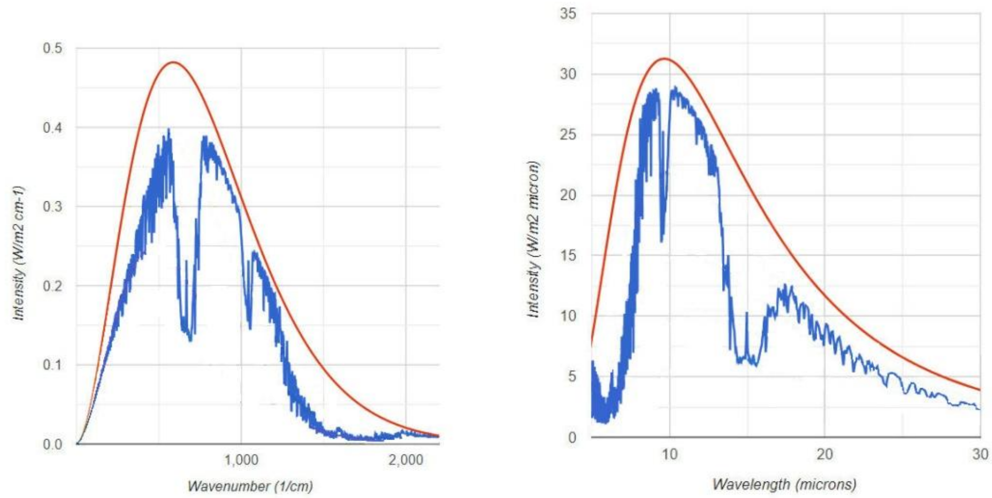


FIGURE 10 – Modtran spectral data using Wavenumber and Wavelength displays. Both of these graphs plot the same intensity data on the vertical axis. Wavenumber is the inverse of wavelength. To convert wavenumber (cm^{-1}) to wavelength (μ), divide 10,000 by the wavenumber.

EFFECT OF GREENHOUSE GAS CONCENTRATION

As discussed earlier in this paper, the presence of so-called "Greenhouse Gases" (often abbreviated to "GHG") in the atmosphere reduces the amount of EM energy that is radiated into space from the earth's surface. The net effect is to increase the total net energy that is absorbed by the surface, thereby increasing the earth's temperature. This additional effective power density at the surface is referred to as "radiative forcing", and is measured in W/m^2. Hitran and Modtran allow the amount of forcing to be determined for various atmospheric conditions and concentrations of GHG.

In December of 2020, a ground-breaking paper was published by W.A. van Wijngaarden of York University and W. Happer of Princeton University entitled: "Dependence of Earth's Thermal Radiation on Five Most Abundant Greenhouse Gases".[11] The researchers used Hitran to predict the effect of various concentrations of Water Vapour, Carbon Dioxide, Ozone, Nitrous Oxide, and Methane in the atmosphere, and then used satellite spectral measurements to confirm the data. Figure 11 below is a simplified version of Figure 4 in their paper, with extraneous information removed. They have used Hitran to look from an altitude of 86 Km at the energy density originating at the earth's surface as a function of Wavenumber (the inverse of wavelength). The blue curve shows a typical black body radiation curve for a body at 288 K in the absence of any atmospheric greenhouse gases. The green curve shows the energy radiated with normal concentrations of all greenhouse gases, but with the CO_2 concentration set to zero. The black curve is the same, but with a 400 ppm CO_2 concentration level. The red curve is the same, but with the CO_2 concentration increased to 800 ppm.

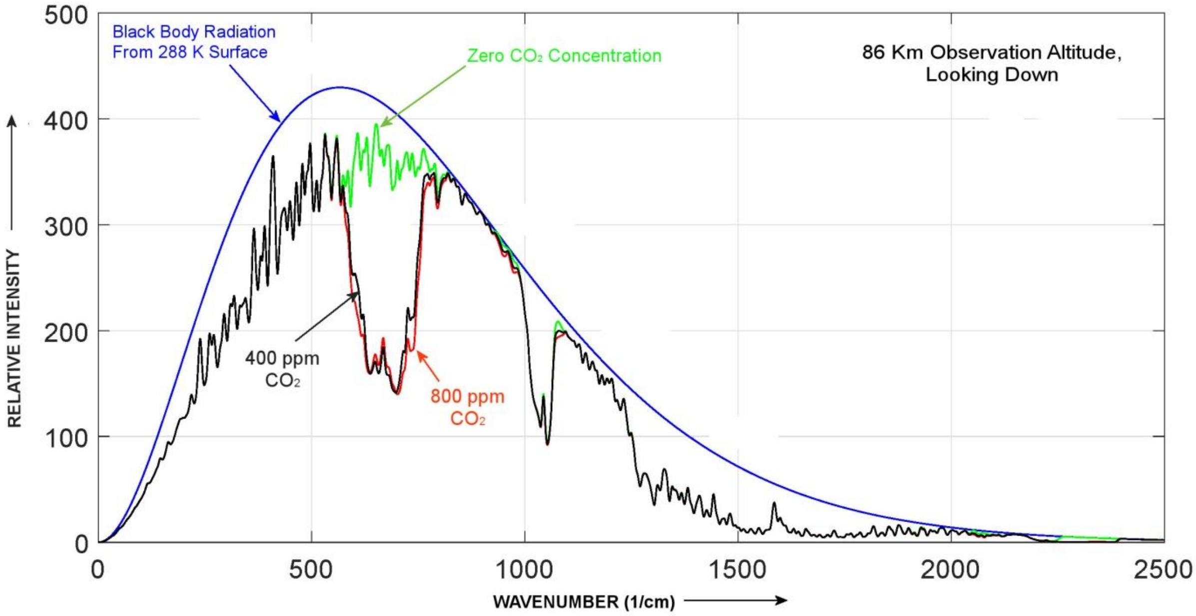


FIGURE 11 – Effect of CO_2 concentration on the upward energy density at the top of the atmosphere. This graphic is a simplified version of Figure 4 from the Wijngaarden and Happer paper, with extraneous information removed. This shows the effect of varying CO_2 concentrations, while other GHG concentrations are kept constant.

In examining Figure 11, look at the "area under the curves". The total area under the blue curve indicates the energy density being radiated from the surface of the earth in the absence of any greenhouse gases. The area under the green curve shows the effect of adding normal concentrations of H_2O, CH_4, O_3, and N_2O to the atmosphere, but no CO_2. The black curve adds 400 ppm of CO_2, which is approximately what the normal concentration in the atmosphere was in 2021. The red curve shows the effect of doubling the CO_2 concentration to 800 ppm. It can be seen that the forcing effect of incremental increases to CO_2 concentration is much less at higher concentrations, and this is consistent with the logarithmic effect predicted by the Beer-Lambert Law. The Wijngaarden and Happer paper determined that the difference in area under the red curve compared to the area under the black curve, which corresponds to a doubling of CO_2 concentration was a "forcing" of 3.0 Watts/m^2.

The Wijngaarden and Happer paper included similar analysis for the other greenhouse gases. In each case, all concentrations were held constant, except the gas being examined. The researchers determined that the radiative forcings resulting from a doubling of the "normal" concentrations were as follows:

H_20	8.1 W/m^2
CO_2	3.0 W/m^2
O_3	2.5 W/m^2
N_2O	1.1 W/m^2
CH_4	0.7 W/m^2

TABLE 1 – Radiative Forcings caused by a doubling of specific greenhouse gases in the atmosphere

The temperature effect of these radiative forcings due to a doubling of concentration is not straightforward, as it needs to include feedback effects and the change in vertical temperature profile in the atmosphere in order to restore "radiative-convective equilibrium". This is discussed at length in the Wijngaarden and Happer paper, where it is calculated that a doubling of CO_2 concentration (resulting in a 3.0 W/m^2 increase of radiative forcing) will result in an increase in the earth's surface temperature of 1.4 to 2.3 degrees C, depending on the water vapour profile. As mentioned, the paper's authors used the sophisticated computer tool and database known as "Hitran" for their research. It is also possible to use a simple tool like the freely available and easy-to-use (but less sophisticated) program known as "Modtran", and achieve results that agree within about 10% of Wijngaarden and Happer's numbers.

In order to explore the sensitivity of radiative forcing to the atmospheric concentration of CO_2, Modtran was used to plot changes in upward IR heat flux from the earth's surface as the concentration was varied. All other concentrations and program parameters were left at their default values. What was calculated was the upward infrared energy flux from the earth's surface, looking down from an altitude of 70 Km. The computed results from Modtran were "normalized" to a reference value that coincides with the flux associated with a CO_2 concentration of 425 ppmv., and the results are plotted in Figure 12.

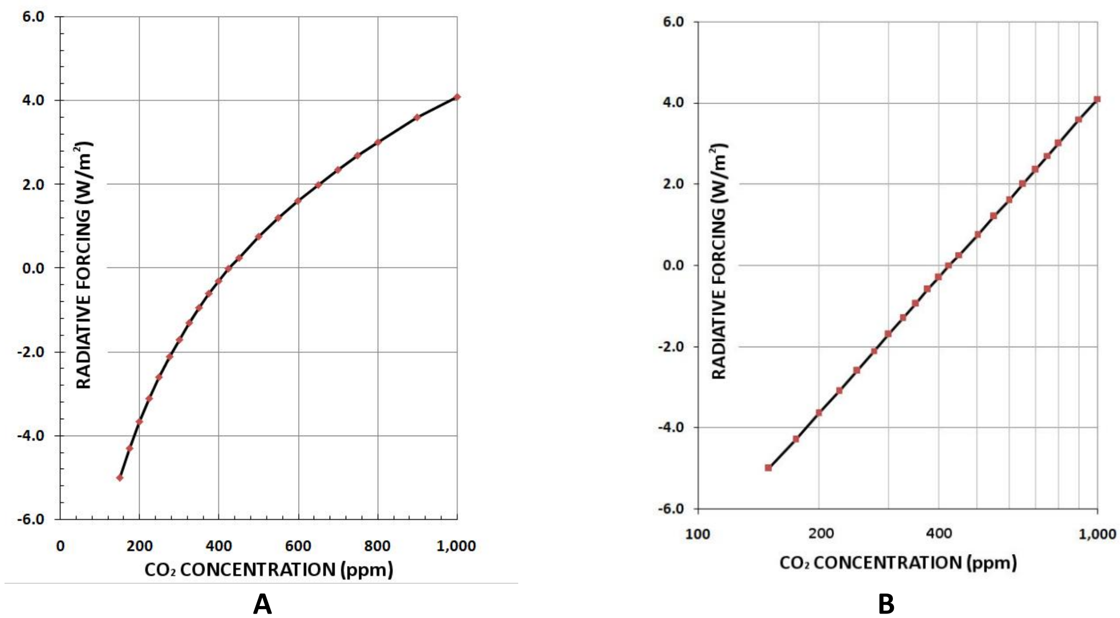


FIGURE 12 – Radiative Forcing as a function of CO_2 concentration in the atmosphere

The same data is plotted in both graphs, using either a linear CO_2 concentration scale (panel A), or a logarithmic scale (panel B). This illustrates the logarithmic response to concentration changes, as predicted by the Beers-Lambert Law.

Figure 12A is plotted with a linear horizontal axis showing atmospheric CO_2 concentrations of between 150 and 1000 ppmv. Below 150 ppm, vegetation would not be able to survive on the earth, and all the previous assumptions become invalid. The plotted curve clearly indicates the logarithmic effect of CO_2 concentration that is described in the Beers-Lambert Law (sometimes referred to as the "Saturation Effect"). This is reaffirmed in Figure 12B, which plots the same data using a semi-log graph.

Using the data that is plotted in Figure 12, we can look at the slope of the curve about the CO_2 concentration values of 425 ppmv (roughly equal to today's ambient value), and observe that the effect of small changes to the concentration is approximately equal to 20 milliwatts/m^2 for each ppm of additional CO_2 concentration in the atmosphere. Using the same argument and assumptions as used in the Wijngaarden and Happer paper, this will result in a global temperature increase of 9 to 15 millidegrees C for each ppm of additional CO_2 concentration in the atmosphere, depending on the water vapour profile Both of these approximations are useful in analyzing various future scenarios, so they are highlighted below:

Sensitivity to changes in atmospheric CO_2 concentration from a starting value of 425 ppm:	
Radiative Sensitivity:	~ 20 mW/m^2 per ppm change in atmospheric CO_2 concentration
Temperature Sensitivity:	~ 9 to 15 mdeg C per ppm change in atmospheric CO_2 concentration
Note – these are approximations only, and are intended to evaluate the effect of small changes to the atmospheric CO_2 concentration about nominal values of 425 ppm.	

As a useful "rule of thumb" for evaluating the effect of various proposed programs, the approximation can be stated in a different manner, as presented in the red box below:

The earth's temperature increases by between 9 and 15 thousandths of a degree C for every 1 ppm increase in the atmospheric CO_2 concentration (*depending on the amount and distribution of water vapour*).

CARBON DIOXIDE

Carbon Dioxide (CO_2) is just one of the five major greenhouse gases. It is the second most abundant greenhouse gas, as illustrated in Figure 13. It is the component that receives most of the publicity (usually negative), and that governments are trying to control through legislation.

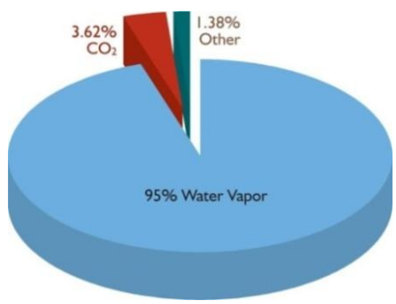


FIGURE 13 – Major Greenhouse Gases

The current concentration of atmospheric CO_2 is approximately 410 parts per million (ppm) by volume. It has been much higher in the past during the Jurassic and Cambrian periods (before the K-T event). Since the K-T Event, the concentration slowly declined from about 1500 ppm to about 250 to 300 ppm during the cyclic ice ages, and started increasing again a few hundred years ago. The concentration has reached just over 410 ppm in 2023. The current rate of rise is slightly over 2 ppm per year.

In March of 2021, a paper appeared in the "Annual Review Of Earth And Planetary Sciences" journal which was entitled "Atmospheric CO_2 Over The Past 66 Million Years From Marine Archives" [12]. The authors estimated atmospheric CO_2 concentrations by analyzing boron isotopes and alkenones from marine sediments, and compared them to other proxies with good correlation. Figure 14 presents the composite data in a chart that is derived from Figure 8 of the paper.

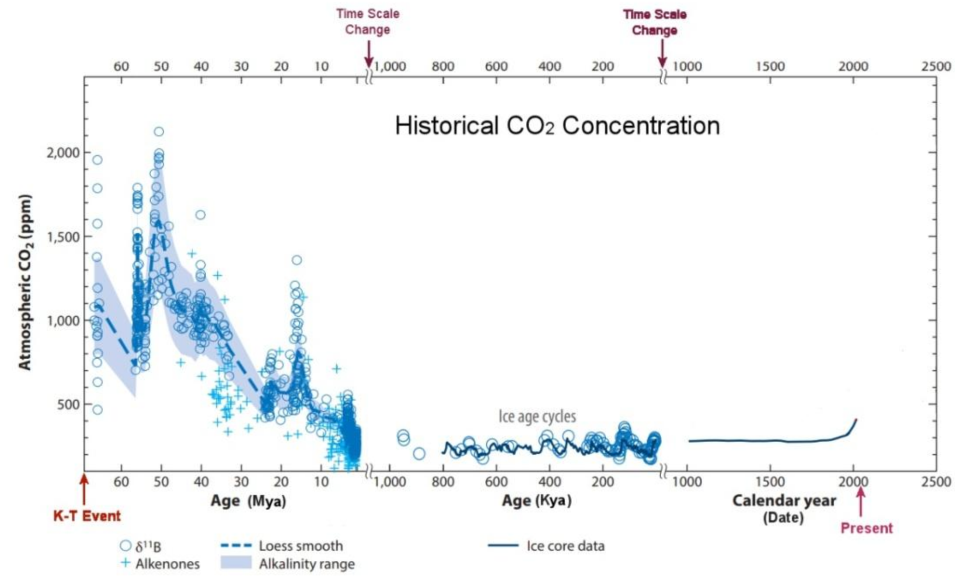


FIGURE 14 – 66 Million Years Of Historical CO_2 Concentration Data From Marine Samples. This chart shows historical CO_2 concentration estimates from marine sediments using Boron Isotopic analysis (circles), Alkenones (crosses), and Ice Core data (straight line). Note the Horizontal time scale changes.

Turning now to more recent times, it is instructive to compare the plots of surface temperature and CO_2 concentration over the past few hundred thousand years, using Antarctic ice core sample data. Figure 15 compares these two parameters.

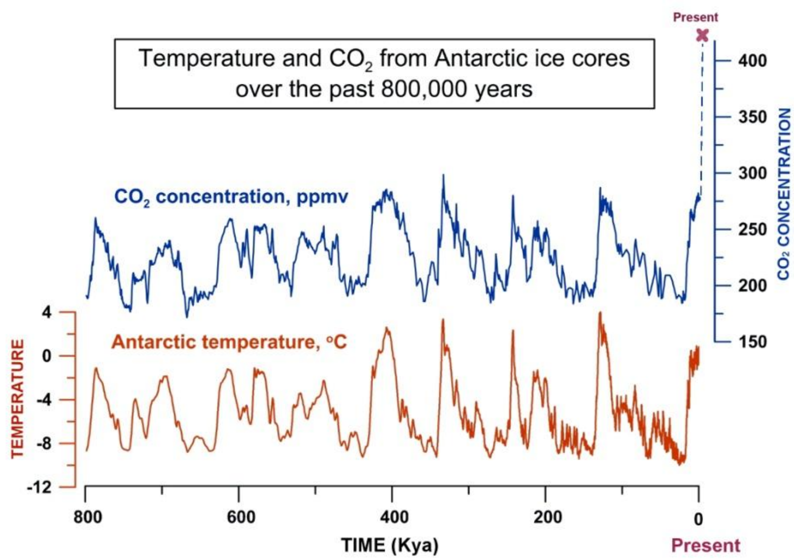


FIGURE 15 – Temperature and CO2 Concentration From Antarctic Ice Cores

The horizontal scale represents thousands of years before the present. This <u>appears</u> to show a very strong correlation, but there is still much debate as to whether or not the temperature changes occur before or after (by several hundred years) changes to the CO_2 concentration. In other words, did changes to the CO_2 concentration cause changes **<u>to</u>** the global temperature, or were the CO_2 concentration changes caused **<u>by</u>** the changing temperature? A closer examination of the data shows that CO_2 concentrations actually start to increase about 800 years **<u>after</u>** temperatures start to rise. It is known that increasing temperatures cause CO_2 outgassing from soil and the oceans, so either hypothesis is possible.

In 1993, the Greenland Ice Sheet Project 2 (GISP2) completed 5 years of coring through the ice, all the way to bedrock. The resulting ice core (3 Km long) was analyzed using isotope ratio techniques to determine the temperature throughout the Holocene. Figure 16 shows the data, together with historical CO_2 concentration derived from ice cores taken in Antarctica (EPICA Dome C). There is a remarkable lack of correlation.

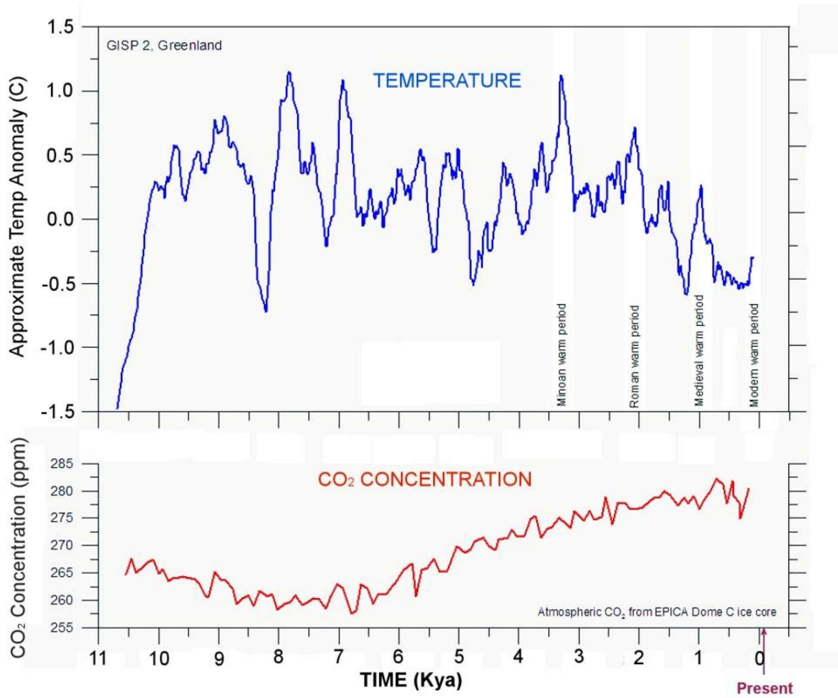


FIGURE 16 – Temperature and CO2 Concentration During the Holocene. Ice cores in Greenland and Antarctica were analyzed to provide this data. There does not appear to be a correlation between temperature and CO2 concentration during this period.

CO_2 is a colourless and odourless gas. It is used by plant life for photosynthesis. If the atmospheric concentration were to fall below about 150 ppm, plant life on earth would cease to exist. Many European greenhouses intentionally artificially increase the CO_2 concentration in order to stimulate the growth of the plants inside. Atmospheric CO_2 is part of the earth's "Carbon Cycle", whereby carbon is transformed between many different forms as part of naturally-occurring cyclical processes. The Carbon Cycle is a complex, much studied, but poorly understood process. Note that popular literature often talks about "Carbon" (a solid) when they are actually referring to CO_2 (a gas). Carbon is the sixth element in the periodic table, and the total number of Carbon atoms in, on, and around the earth is <u>fixed</u> (in the absence of nuclear reactions). Although the number of Carbon atoms is fixed, it can exist in combination with other elements to create the various forms that we are familiar with (vegetation, animal and human life forms, calcites, diamonds, hydrates, fossil fuels, Methane, CO_2, etc). A greatly simplified illustration of the carbon cycle is shown in Figure 17.

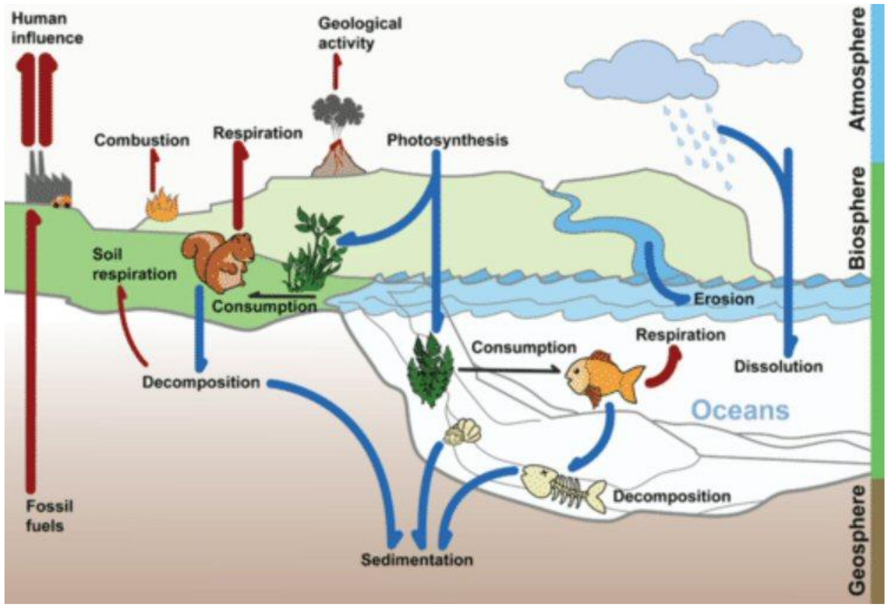


FIGURE 17 – The Carbon Cycle. In looking at this diagram, it is important to recognize that the amount of carbon remains constant, but it is just manifesting itself in different forms in a continuous, cyclic process.

Many human activities result in the release of CO_2 into the atmosphere.[13] The dominant ones are those involving the combustion of fossil fuels. Typical sources are heating, internal combustion engines, external combustion engines (thermal power plants), cement production, and industrial processes. There are also many natural mechanisms that release CO_2 into the atmosphere: the decay of organic material, respiration, dissolution, calcification, outgassing, fires, volcanoes, etc. CO_2 is taken out of the atmosphere by other natural "sink" phenomena: photosynthesis and absorption into water being the major mechanisms. The current estimates are that 4 to 5 percent of the current atmospheric CO_2 is due to human activities. This implies that the atmosphere contains 16 to 21 parts per million of man-made CO_2.

There have been many studies to estimate the emissions of anthropogenic CO_2 by sector, and its disposition amongst various "sinks". One exceptionally detailed study was published by Earth System Science Data in 2022, entitled "Global Carbon Budget 2022".[14] Figure 18 is an illustration taken directly from Figure 3 of the paper.

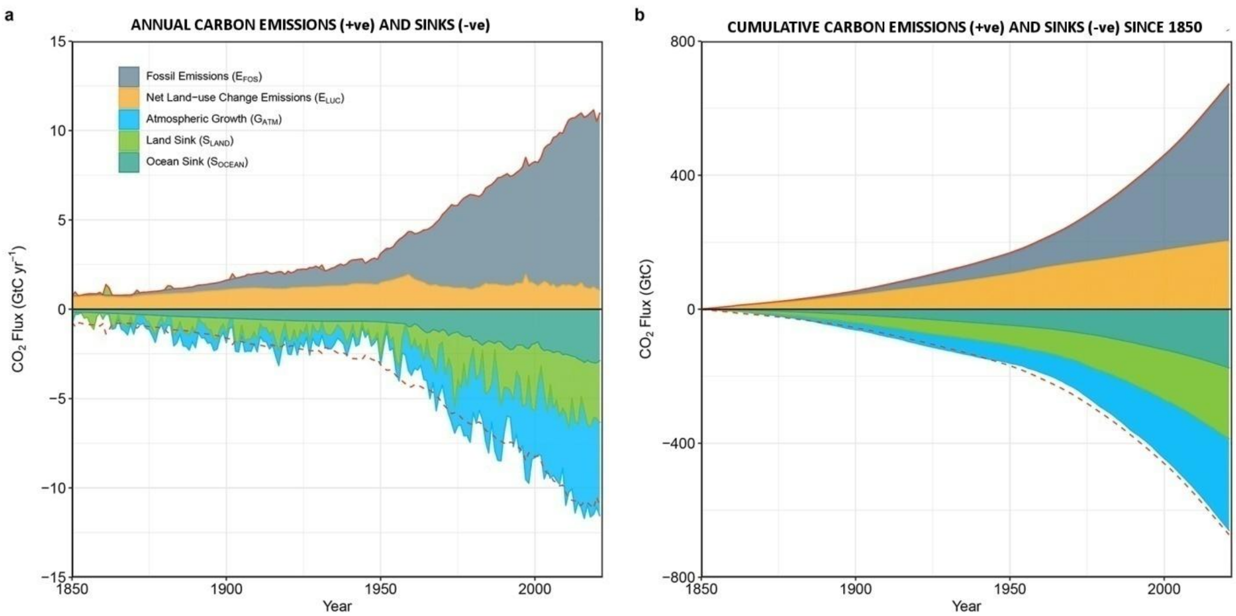


FIGURE 18 – The Global Carbon Budget. The left figure shows global annual anthropogenic emissions (above the horizontal axis), and corresponding sinks (below the line). The right figure shows cumulative data since 1850. Note that these are plotting Gigatonnes of Carbon. To convert to Gigatonnes of CO_2, multiply by 3.66. To convert Gigatonnes of Carbon to equivalent ppmv of CO_2, multiply by 2.12. The dotted red line below the horizontal axis reflects the inverse of the summation above the line. The fact that the dotted line does not exactly line up with the bottom of the blue area is an artefact of the multiple data sources that were used.

Note that Figure 18 is plotting the mass flux of carbon. Multiply by 3.7 to get the equivalent values of CO_2 mass. This is a confusing state of affairs, and results in the media stating that "we have to take the carbon out of the atmosphere", despite the fact that carbon is a solid and CO_2 is a gas! Figure 18 is drawn so that the total area below the horizontal axis is the same as the area above the axis: the blue "Atmosphere Growth" is defined in such a way to make the balance equal zero. In other words, the total area of the blue is indicative of the amount of anthropogenic CO_2 in the atmosphere.

There are many sources of anthropogenic CO_2. Here is a breakdown of the main contributing sectors, as outlined by Hannah Ritchie and Max Roser in a summary entitled "Greenhouse Gas Emissions"[15]. These are global numbers, for the year 2016:

Energy Production For Transport:	*Road (cars, trucks)*	11.9%
	Aviation	1.9%
	Ships	1.7%
	Rail and pipeline	0.7%
Energy Production for Industry		24.2%
Energy Production for Buildings		17.5%
Energy Production (other)		15.3%
Industrial Processes (concrete, chemicals)		5.2%
Waste (landfills, wastewater)		3.2%
Agriculture, Forestry, and Land Use		18.4%

The so-called "Keeling Curve" is a plot of the atmospheric CO_2 concentration measured daily at the Mauna Loa Observatory on the island of Hawaii since 1958. The observatory is at an altitude of 3,400 metres, and measurements are made using a non-dispersive infrared photometer. Figure 19 is the plot from 1958 to September 7th, 2023 [16].

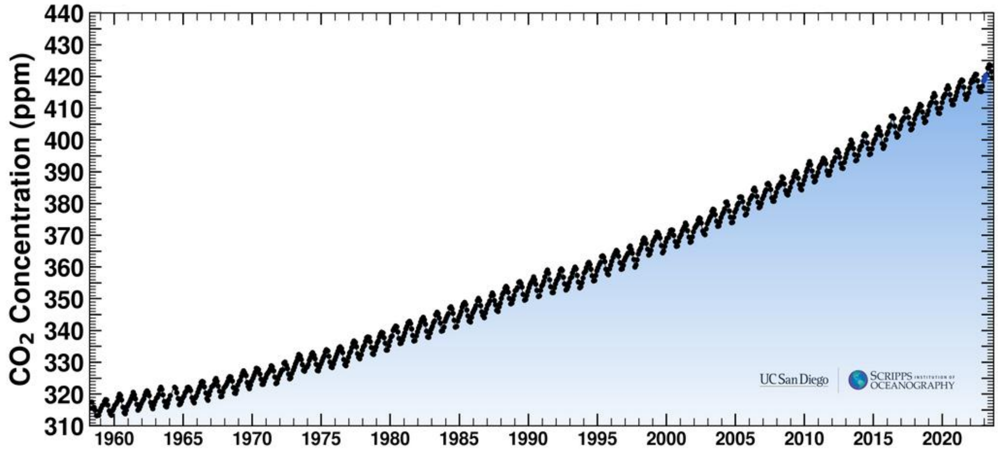


FIGURE 19 – The Keeling Curve. This chart plots the concentration of atmospheric CO_2 measured daily at the Mauna Loa Observatory in Hawaii.

Figure 19 shows a steady rise of CO_2 concentration during the measurement period. It also shows a cyclical variation of approximately 6 ppm every year due to the seasonal change in uptake of CO_2 by the world's land vegetation. The atmospheric level is highest in May, and then it decreases during the northern spring and summer as new plant growth takes CO_2 out of the atmosphere due to photosynthesis. The atmospheric level is lowest in September, and then it rises again through the northern fall and winter as plants and leaves die off and decay.

Many people believe that the continuous rise in atmospheric CO_2 is primarily due to human activities, but the Keeling plot does not show any reduction in slope during 2020 and 2021, when the Covid pandemic caused a major reduction in industrial operations.

There is controversy over the lifetime of CO_2 in the atmosphere. Estimates have varied from 5 to over 1,000 years, but the 1963 treaty banning atomic tests allowed scientists to track the fall in CO_2 concentration containing the ^{14}C isotope from the time of the cessation of testing. This decay followed an exponential decline, falling to 1/e of the initial value within about 20 years. If placed in a sealed container, CO_2 has a very long life. As described above, the "carbon cycle" involves CO_2 being released into the atmosphere at the same time that it is being taken out through the various "sink" processes. The concentration of any "new" CO_2 in the atmosphere will appear to decay exponentially as it is slowly cycled through the various sink and emission mechanisms. Approximately every 20 years, the detectable concentration of any "new CO_2" in the atmosphere will be reduced to a factor of 1/e (approximately 37%). To better understand this, consider the following analogy:

Imagine a swimming pool that has a system which is adding fresh water at the rate of one "pool's worth" of water every 10 days, and a system that is draining out water at the same rate. The casual observer would state that the water is completely exchanged every 10 days, but that is not actually the case! Now let's dump in a container of red dye that represents 1 ppm of the volume in the pool. The pool water would take on a red hue, but our casual observer would say that it *will have completely cleared up in 10 days. However, when we measure the dye concentration 10 days later, it is not zero, it is 0.37 ppm!*

Every 2.4 hours, 1% of the water is "exchanged". Therefore, after 2.4 hours, the red dye concentration will have been reduced to 0.99 ppm. After a further 2.4 hours, it will be reduced to 99% of 0.99 ppm, etc. If you add up the series, you will find that after 100 of these time periods (totalling up to 10 days), you have approximately 1/e times the original 1 ppm concentration. [Note: e is 2.71828 ....., which is the base for natural logarithms]

Many observers will look at the <u>*initial rate*</u> *of red dye depletion, and extend it using a straight line to declare when "all the bad stuff will be gone". This is incorrect, because the curve is exponential, not linear.*

Another good analogy is to look at the shape of the voltage discharge curve of a 1 microfarad capacitor in parallel with a 1 megohm resistor. Imagine that the capacitor is initially charged to 1 volt. The so-called "Time Constant" is 1 second (R x C), and the <u>*initial rate*</u> *of discharge suggests that the capacitor will be completely discharged after 1 second, but the measured voltage after 1 second is actually 370 millivolts, which is 1/e times the initial voltage. A plot of the actual voltage as a function of time will follow the classical exponential discharge curve, which never reaches zero, but is asymptotic to it.*

If we look at the shape of the $^{14}CO_2$ *concentration after the cessation of open air atomic bomb testing, the curve is exponential, and the concentration had fallen to about 1/e of its starting value after about 20 years. We therefore inferthat the "residence time" of* CO_2 *in the atmosphere is 20 years!*

The oceans absorb CO_2. The amount that is absorbed varies with temperature, in accordance with Henry's Law. An equilibrium is established across the air-water interface, depending on the partial pressure of atmospheric CO_2.

ORBITAL MECHANICS

As described earlier, the power density of the solar energy arriving at the top of the atmosphere varies inversely as the square of the distance to the sun. Variations in the sun-to-earth distance will definitely affect the energy arriving at the earth. The average distance is 147 million Km, but the earth's orbit around the sun is not a perfect circle, it is actually an ellipse. The eccentricity of the orbit varies cyclically with a period of about 405,000 years due to the gravitational effects of Saturn and Jupiter. This changing eccentricity is just one of several different changes in orbital mechanics that are known as Milankovitch Cycles[17].

The three main Milankovitch Cycles are: orbital Eccentricity, Obliquity (Tilt), and Precession. These are illustrated in Figure 20.

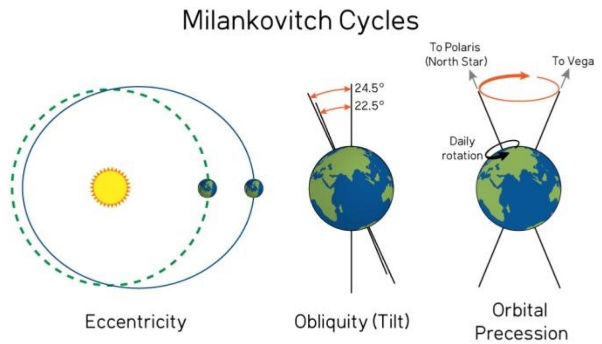


FIGURE 20 – MILANKOVITCH CYCLES. These are cyclical changes to the Earth's orbital parameters as it spins and travels around the Sun.

If the earth's surface was completely covered with land of a constant albedo (reflectivity), the fact that the Obliquity and Precession change over time would have no effect at all on the global temperature. However, the earth's surface can be either land, water, or ice, and these all have very different albedos. In addition, the land proportion is much higher in the Northern hemisphere than in the Southern hemisphere, so the amount of heat absorbed in either the local summer or winter by the two hemispheres will vary depending on the orientation changes due to Tilt and Precession. The three different orbital parameters vary with different periods:

Eccentricity	405 K years and 100 K years
Obliquity	41 K years
Precession	25.7 K years

In addition to these three Milankovitch Cycles, there are also cyclic orbital variations due to Apsidal Precession, and Orbital Inclination. All of these cyclical variations combine to cause a repetitive variation that has several different frequency components, as shown in Figure 21.

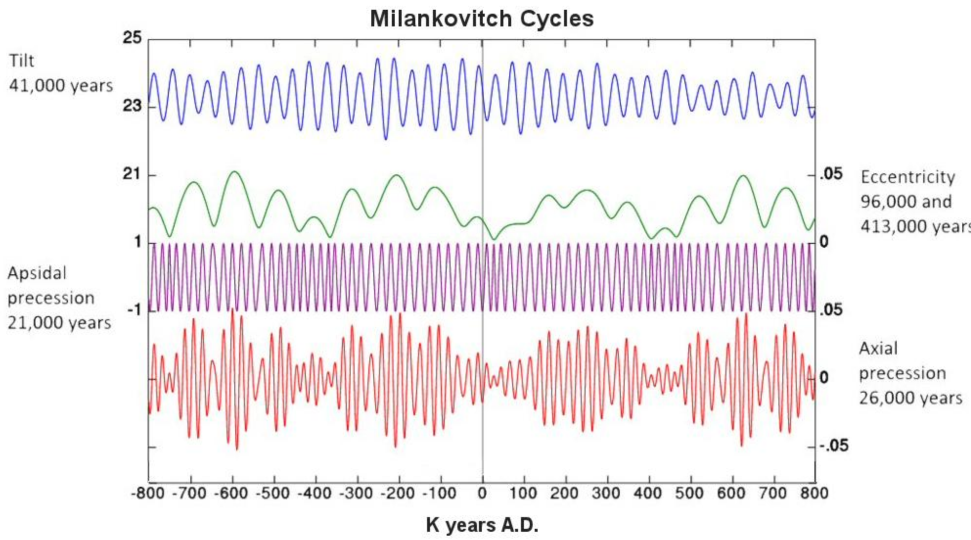


FIGURE 21 – Milankovitch Cycle Periodicity

These Milankovitch Cycles combine, to cause an overall "modulation" of the solar energy density arriving at the top of the earth's atmosphere. This thermal energy is referred to as "Insolation", and is shown in Figure 22 for a Latitude of 65 N at the summer solstice.

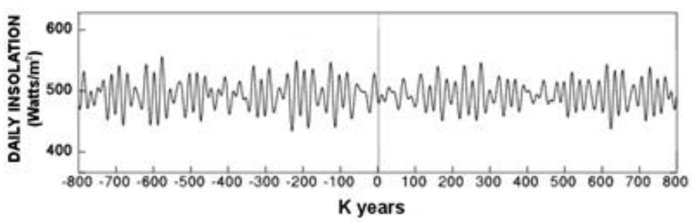


FIGURE 22 – Summer Solstice Insolation at 65N. This is the net effect of the combination of all the individual Milankovitch cyclic frequency components.

The effect of these insolation changes can be clearly seen in the core sample thermal data shown in Figure 3 earlier in this document. The effect of obliquity by itself can clearly be seen in the Holocene temperature record, as shown in Figure 23.

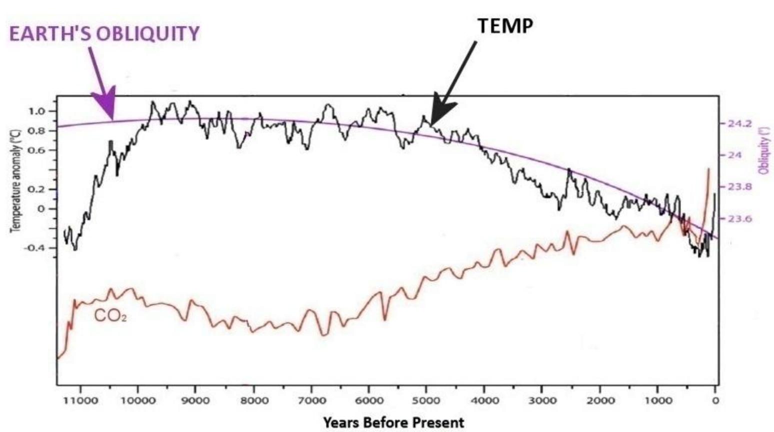


FIGURE 23 – Correlation Between Temperature and Obliquity During the Holocene

CONTINENTAL DRIFT, OCEANS & CURRENTS

Oceans play an important part in controlling or changing the earth's climate. They store energy, transport energy, and absorb and/or release CO_2. Water's Specific Heat is much greater than that of the rocks or soil commonly found on land. The average albedo of land is about 0.3, but the albedo of the oceans is about 0.06. This means that the oceans absorb much more (per unit surface area) of the sun's energy than the land[18]. The best way to interpret this is to consider that the solar energy which warms the land is actually primarily collected by the oceans, and then distributed by oceanic currents.

Oceans have a thermocline that separates the warmer, well-mixed surface waters from the deeper cold waters. The thermocline depth is usually in the range of 200 to 1,000 metres. The colder water underneath the thermocline stores large amounts of CO_2 as well as other minerals.

Ocean currents are the dominant mechanism for heat transfer on the earth, and these currents have changed radically over the long term as the continents have moved due to plate tectonics. The earth used to have just a single, large continent known as "Pangea", and it was surrounded by the Tethys Sea. About 195 Mya, during the Jurassic Period, the super-continent of Pangea started to break up, as shown in Figure 24. The fault lines between tectonic plates are shown, and the arrows indicate the direction of motion.

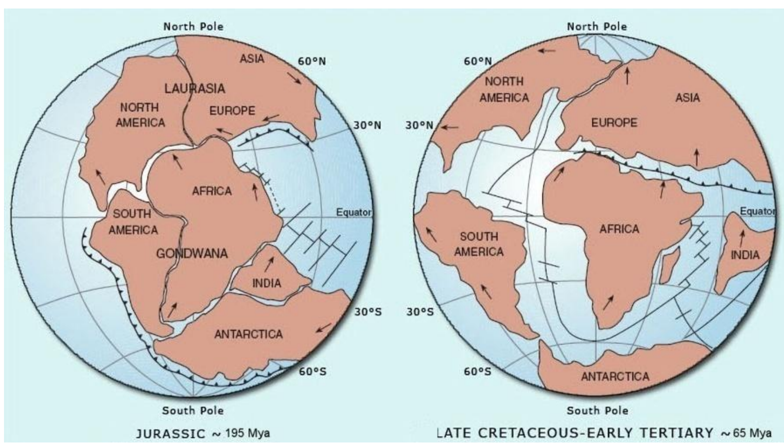


FIGURE 24 – The Break Up of Pangea Due to Continental Drift

As the continents have drifted, ocean passages have opened and closed over time. As a result, there have been major changes in ocean currents, and this has affected energy collection and transportation, and hence climate. We will examine this more closely, starting 66 Mya, right after the K-T event. We will be using a series of images created by C. R. Scotese as part of his Paleomap Project, which researched and illustrated the plate tectonic development of the ocean basins and continents, as well as the changing distribution of land and sea during the past 1.1 billion years. Figure 25 shows the situation just after the asteroid hit the earth at Chicxulub.

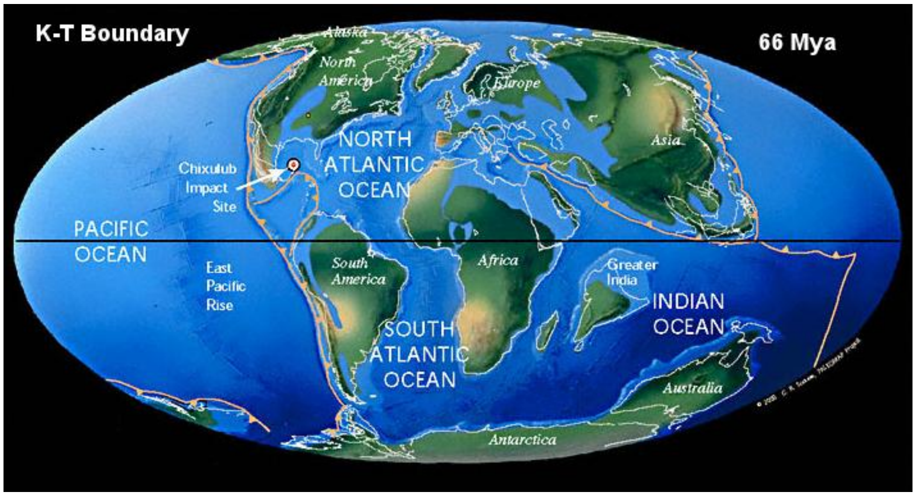


FIGURE 25 – Continental Positions Right After the K-T Event

At this point of time, there is no sea passage between Antarctica and South America or Australia. The Panama Isthmus is wide open, and there are open passages North of Africa and South America that allowed an equatorial current to circulate around the warmest part of the globe, distributing heat. There were no ice caps, and life was abundant. Figure 26 illustrates the Equatorial Current that existed at the start of the Eocene.

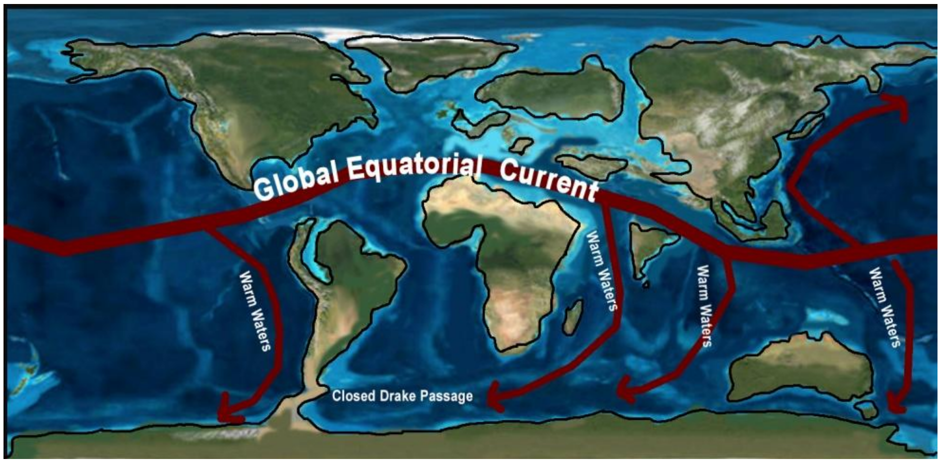


FIGURE 26 – Ocean Currents During the Eocene

In Figure 27, we look at the earth at about 50.2 Mya, in the middle of the Eocene Epoch.

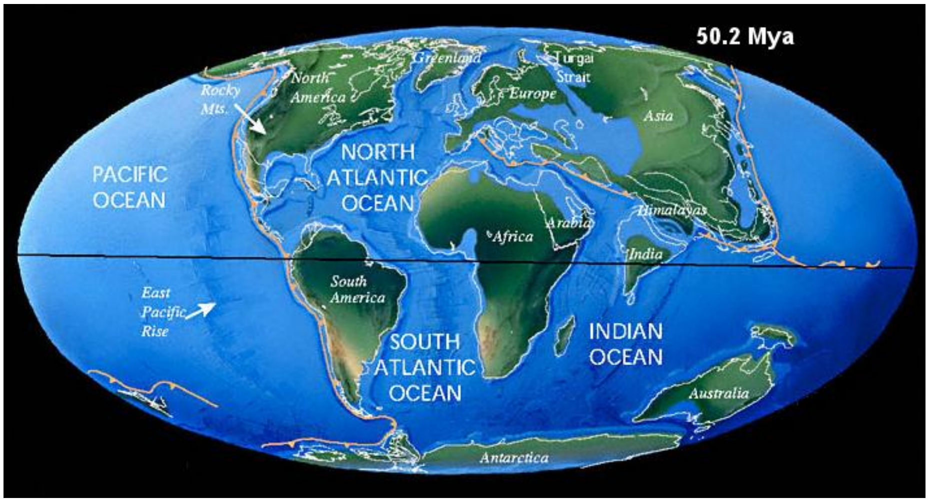


FIGURE 27 – Continental Positions in Mid-Eocene

The dinosaurs have died out, Australia has separated from Antarctica, India is moving rapidly toward Asia, and the Himalayan and Rocky Mountains are forming. The Drake Passage between South America and Antarctica is opening, and the Straits of Gibraltar are narrowing. The equatorial current is getting constricted, resulting in cooling.

Later in geological time, Figure 28 shows the continental positions in the middle of the Miocene, at 14 Mya.

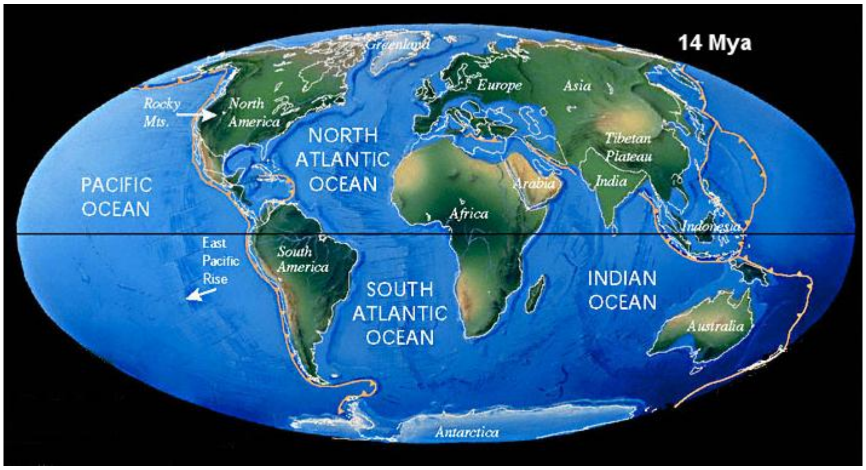


FIGURE 28 – Continental Positions in Mid-Miocene

The cooling has continued, and there is significant ice on Antarctica. India has joined up with Asia, the Gibraltar Strait is quite restricted, and the Panama Isthmus is almost closed. Florida and parts of Asia are under water. The equatorial current is mostly blocked, and the Antarctic Circumpolar Current circles around Antarctica. The Arctic is still ice-free.

At about 3 Mya, the Panama closes, and the Equatorial Current can no longer circulate, causing the start of a general cooling trend at the start of the Pleistocene. (Note – recent research has suggested that the Panama might have closed much earlier: perhaps 18 Mya). For the past 800 thousand years, the earth has gone though a repetitive series of glaciations, as illustrated in Figure 3 earlier in this document.

Figure 29 shows the situation 18 Kya, at the Last Glacial Maximum (LGM).

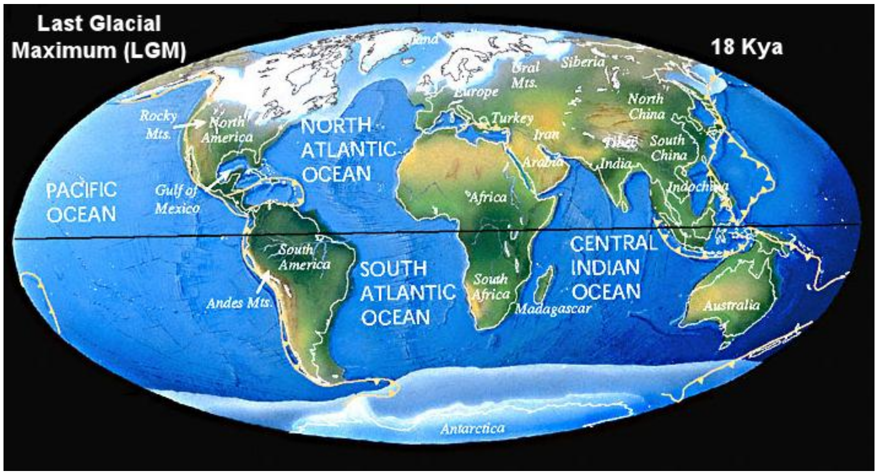


FIGURE 29 – Continental Positions at the Last Glacial Maximum (LGM)

The continents are in their modern, familiar positions, although the shorelines are considerably seaward due to the lower sea level as a result of the glaciations. Homo Sapiens are well established, and land bridges allow intercontinental migrations. The Mediterranean Sea is completely isolated, and the Indonesian area blocks major current flows between Asia and Australia. Northern Europe and Canada are almost completely covered in ice, and the Antarctic ice sheet extends Northward almost all the way to Tasmania and South America.

The Tectonic Plates are continuing to move, and the continents will slowly drift and form a new "super continent" referred to as Pangaea Proxima in about 250 million years time.

In modern times, energy is distributed via what is known as the "Ocean Conveyor"[19], whose route has been defined by the moving continental land masses. Figure 30 shows the flow.

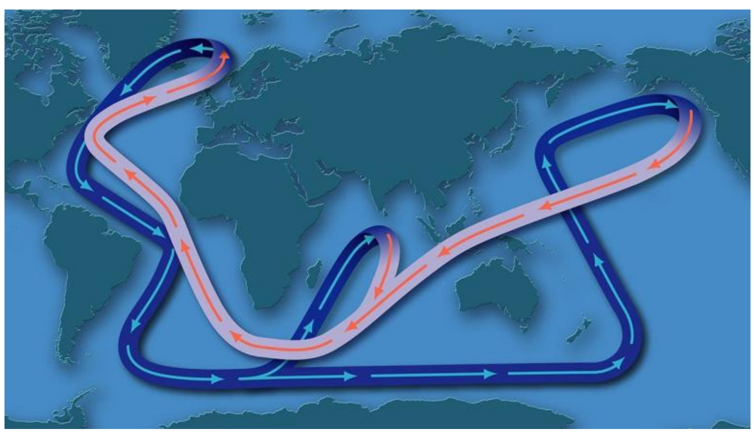


FIGURE 30 – The Ocean Conveyor
(From Woods Hole Oceanographic Institution)

The Ocean Conveyor is a continuously-circulating current that goes by different names in different parts of the world, but it is driven by changes in density due to salinity variations, and it is the major transporter of solar energy throughout the globe. Warm, salty surface water from the Caribbean, the Gulf of Mexico, and Western Africa flows Northward in the Gulf Stream. As it passes through Northern latitudes, it gives up heat and moisture to the atmosphere. By the time it arrives in the North Atlantic, the water has become cool and salty, thereby increasing its density. This dense water sinks to the ocean floor, and flows southward as a current that passes underneath the Gulf Stream, continuing on the

Southern Ocean, then to the Indian and Pacific Oceans, where it eventually mixes with warm water, rises, and returns to the Atlantic to complete the circuit.

A fundamental driver of the Ocean Conveyor is the difference in salinity between the Atlantic and Pacific Oceans. When the Panama was open, waters could freely mix between the Pacific and Atlantic, and there was no salinity difference. After the Panama closed, there was no mixing between the two oceans, and the salinities diverged. Evaporation in the Caribbean and tropical Atlantic caused increases in salinity, and fresh water was put in the atmosphere, where it was carried across to the Pacific by Westerly-flowing Trade Winds, to then fall as precipitation. The net result of this was that the salinity in the Atlantic slowly increased relative to the Pacific. This salinity difference continues to drive the Ocean Conveyor. Contrast the route of the Ocean Conveyor with the Equatorial Current shown earlier in Figure 26.

This discussion illustrates how the earth's overall climate has changed over time due to long term continental drift and the associated changes in ocean currents. There are other, more localized and shorter term current variations that affect climate in the short term: ENSO, PDO, and AMO. We will examine these in detail, starting with ENSO (El Niño-Southern Oscillation)

The El Niño-Southern Oscillation (ENSO) is a recurring climate pattern involving changes in the temperature of waters in the central and eastern tropical Pacific Ocean. On periods ranging from about three to seven years, the surface waters across a large swath of the tropical Pacific Ocean warm or cool by anywhere from 1°C to 3°C, compared to normal.

This oscillating warming and cooling pattern, referred to as the ENSO cycle, directly affects rainfall distribution in the tropics and can have a strong influence on weather across North America and other parts of the world. El Niño and La Niña are the extreme phases of the ENSO cycle; between these two phases is a third phase called ENSO-neutral. There is much conjecture over the root cause of these cycles, including the possibility that underwater volcanoes and sea vents may be involved. Indeed, there is a whole new field of study that was formally launched in 2004 called "Plate Climatology" that combines input from several branches of science: Geology, Climatology, Meteorology, Oceanography, and Biology.[20]

El Niño is warming of the ocean surface, or above-average sea surface temperatures (SST), in the central and eastern tropical Pacific Ocean. Over Indonesia, rainfall tends to become reduced while rainfall increases over the tropical Pacific Ocean. The low-level surface winds, which normally blow from east to west along the equator instead weaken or, in some cases, start blowing the other direction (from west to east").

La Niña is cooling of the ocean surface, or below-average sea surface temperatures (SST), in the central and eastern tropical Pacific Ocean. Over Indonesia, rainfall tends to increase while rainfall decreases over the central tropical Pacific Ocean. The normal easterly winds along the equator become even stronger.

Figure 31 is provided by NOAA, and it illustrates both a strong La Niña (from December 1988) and an El Niño (December 1997).

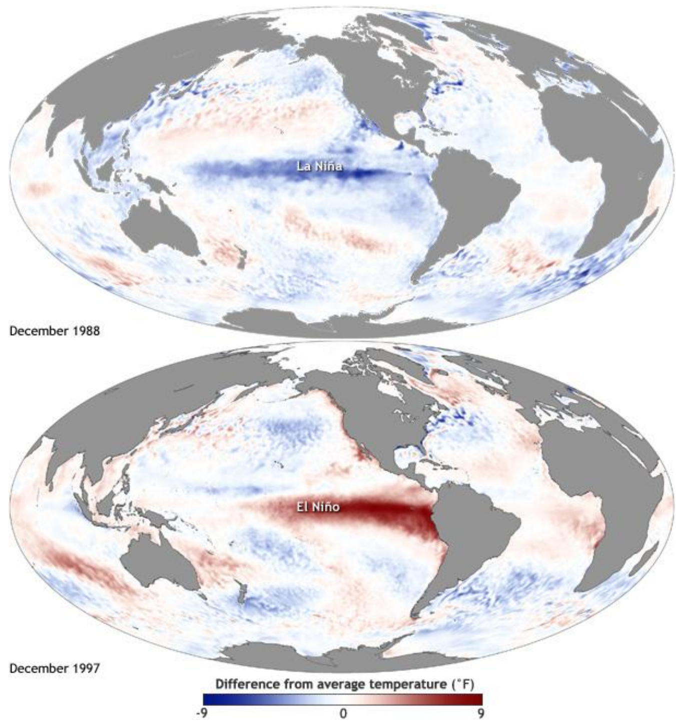


FIGURE 31 - La Niña (top) and El Niño (bottom)

The PDO (Pacific Decadal Oscillation) is more focussed on the Northern Pacific region. The PDO is a long-lived El Niño-like pattern of Pacific climate variability, and extremes in its pattern are marked by widespread variations in the climate of the Pacific Basin and North America. The extreme phases of the PDO have been classified as being either warm or cool, as defined by ocean temperature anomalies in the northeast and tropical Pacific Ocean. The recent historical record of both PDO and ENSO is shown in Figure 32.

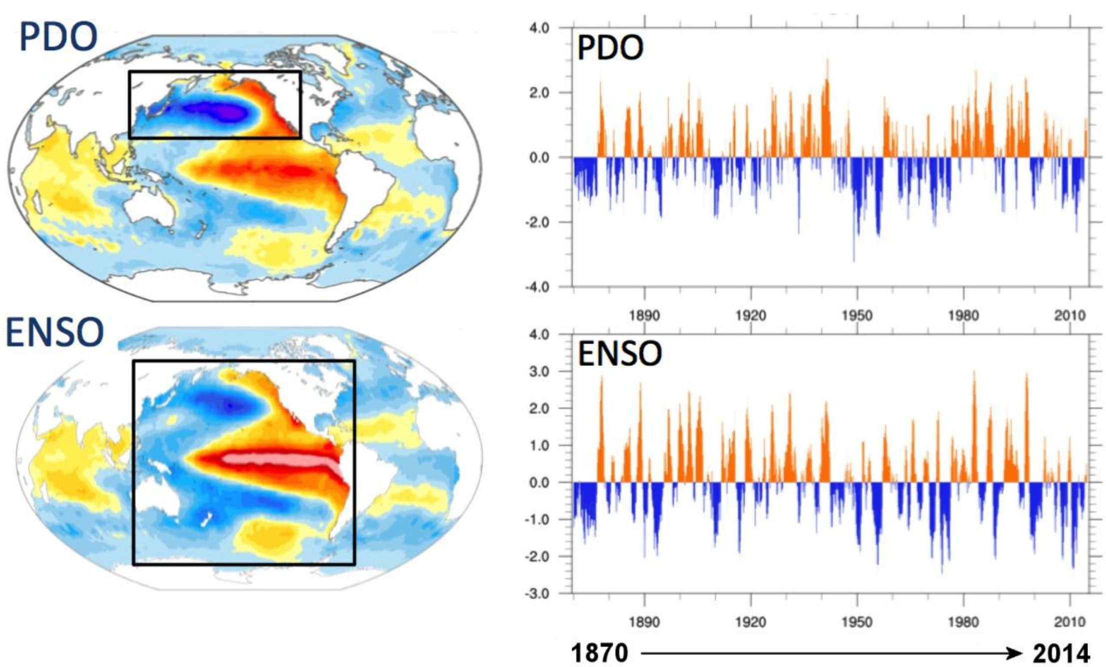


FIGURE 32 – Record of PDO and ENSO Magnitudes

There are similar longer-term temperature cycles in the Atlantic Ocean, referred to as AMO (Atlantic Multi-decadal Oscillations). Figure 33 shows a recent historical record of these temperature swings.

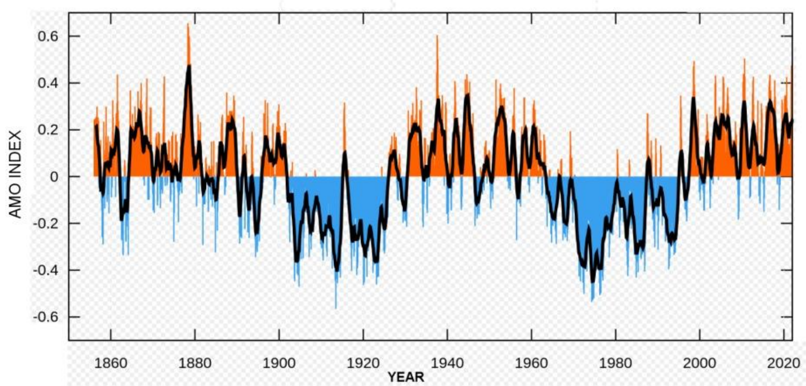


FIGURE 33 – AMO (Atlantic Multi-Decadal Oscillation) Index

GLACIATIONS

There was a period of time when the popular media was making a big issue of the "Retreat Of The Glaciers"

The Earth has been ice-free (even at the poles) for most of its history. However, these iceless periods have been interrupted by several major glaciations (called Glacial Epochs) and we are in one now in the 21st Century. Each glacial epoch consists of many advances and retreats of ice fields. These ice fields tend to wax and wane in about 100,000, 41,000 and 21,000 year cycles (under the influence of Milankovitch Cycles). Each advance of ice has been referred to as an "Ice Age" but it is important to realize that these multiple events are just variations of the same glacial epoch. The retreat of ice during a glacial epoch is called an Inter-Glacial Period and this is our present climate system.

The existing Plio-Pleistocene Glacial Epoch began about 3 million years ago and is linked to the tectonic construction of the Isthmus of Panama which prevented the circulation of Atlantic and Pacific waters and eventually triggered a slow sequence of events that finally led to cooling of the atmosphere and the formation of new ice fields by about 2.5 million years ago.

Thus far, the Earth has had around 15 to 20 individual major advances and subsequent retreats of the ice field in our current Glacial Epoch (see earlier Figure 3). The last major advance of glacial ice peaked about 18,000 years ago at the Last Glacial Maximum (LGM), and since that time the ice has generally been retreating although with some short-term interruptions. What we are presently experiencing in Greenland and other continents is a rapid melting of surrounding sea ice by rising ocean temperatures and a widening of the Gulf Stream. Greenland's continental glaciers are also retreating due to an accumulation of atmospheric soot and a reduction of fresh snow to cover it. Although the earth currently appears to be warming, we will inevitably enter another glacial period in a few thousand years.

SEA LEVEL

There is a great deal of publicity (and in some cases, hysteria) surrounding predicted increases in sea level which will result in wide-spread flooding. If the earth maintains a constant vertical profile, the sea level is purely a function of the total volume of water in the oceans. As the earth's surface temperature increases, not only will the sea's volume and evaporation rates increase, but ultimately ice in the Arctic and Antarctic regions will melt, thereby increasing the volume of water in the oceans, and raising the sea level. Note that the melting of ice that is currently floating in the oceans will not result in an increase in sea level; it is only the ice that is presently on land that will have an effect if it melts.

The press has made much of the claim that "The Glaciers Are Melting", and concluded that this is being caused by man's recent contribution to atmospheric CO_2. However, as described earlier, records show that the recent glacial retreat has been occurring for hundreds of years, and is normal behaviour between glaciations. Figure 34 shows the historical sea level extending back to before the K-T Event.

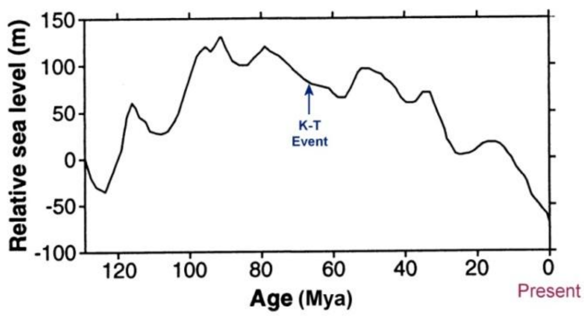


FIGURE 34 – Historical Sea Level Since Before the K-T Event

If the mountain snowpacks and the icecaps on Greenland and Antarctica do melt, there is no doubt that the average sea level will rise. In our particular region (Western Canada), this is offset by the fact that the earth's surface is actually rising due to rebound from the ice ages, and (in the Victoria region) due to tilting of Vancouver Island from relative motion of the plates beneath it.

In South East Alaska, every year more land is actually being "reclaimed" from the ocean as the land rebounds from the heavy ice load it was previously subjected to.

The global average sea level is currently increasing by about 3 mm per year, and this is expected to continue. Figure 35 plots the sea level from a number of different locations since the Last Glacial Maximum (LGM) and through the Holocene to the present.

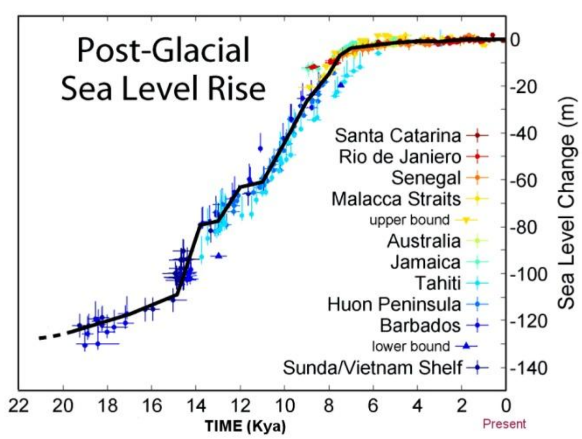


FIGURE 35 – Historical Sea Level Since the Last Glacial Maximum

ENERGY FLOWS

Many reports and climate models use a simple diagram to illustrate the major energy flows associated with determining the earth's temperature. Recall that at the top of the atmosphere, there is an average equivalent perpendicular incoming solar radiation density of 341.3 Watts per square metre (W/m^2). An Energy Flow diagram attempts to map how this insolation flows through the earth's atmosphere, and how much of it is eventually radiated into space either as infrared or visible energy. By its very nature, these diagrams have to use average values for all coefficients, and an example is shown in Figure 36.

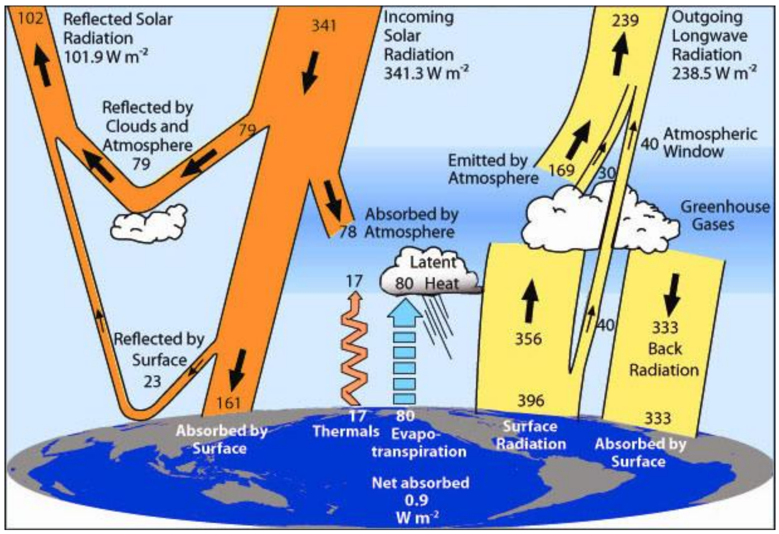


FIGURE 36 – Energy Flow Diagram

Looking at Figure 36, there is a net energy density flow of 0.9 W/m^2 that is absorbed by the earth, which will cause long-term heating, but don't forget that the numbers in this diagram are all estimates, and have significant error bands, so the result should not be taken as certain. In particular, the absorption by the earth is stated as an average value, which has to include all the surfaces (water, land, ice, trees, sand, etc), so this is a questionable value. Also note the large effect that clouds have: again, this is an average value over the whole earth.

For the moment, as a thought experiment, imagine that the earth's reflectivity (it's "Albedo") is constant across its entire surface. Although we know the average incoming solar radiation density (it's "Insolation") is 341.2 W/m^2, it should be obvious that the value will be higher near the equator than it is near the poles. This is illustrated in Figure 37.

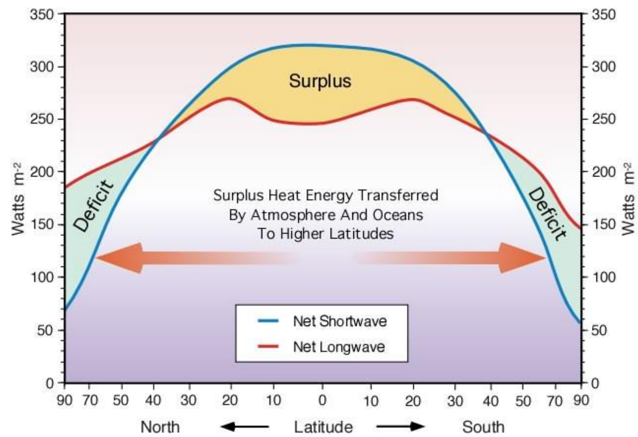


FIGURE 37 – Energy Distribution as a Function of Latitude

Looking at Figure 37, the horizontal axis represents the latitude from the North Pole to the South Pole. The blue line represents the incoming solar energy density, and it is highest at the equator. The red line represents the outgoing energy moving upward from the surface of the earth. The areas under both curves must be roughly equal, so we can say that there is an energy “deficit” near the poles, and a “surplus” near the equator. In order to maintain equilibrium, energy must flow to higher latitudes. This is achieved by the previously-discussed ocean currents, or by winds.

AIR CURRENTS

Most of earth’s weather occurs in the Troposphere, which is the bottom layer of the atmosphere. The top of this layer occurs at the “Tropopause”, which is a thermodynamic gradient-stratification layer that is approximately 17-18 Km high at the equator and 8Km or lower at the poles. Immediately above the tropopause is the TIL (Tropopause Inversion Layer). Clouds are normally formed underneath the tropopause. Figure 38 is a cross section of the atmosphere, using the same horizontal axis configuration as Figure 37.

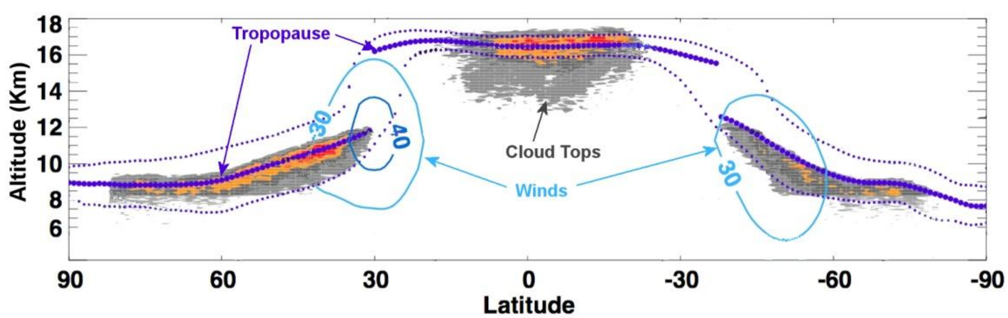


FIGURE 38 – Tropopause As a Function of Latitude

Looking at Figure 38, the small purple dots show 10^{th} and 90^{th} percentile range of the tropopause height. The cloud top fraction density is shown as a colour-coded distribution (grey to red). The light blue lines outline areas of strong winds at the “break” in the tropopause at about 30 degrees North and South latitude, and the numbers represent velocities in metres per second. The tropopause at approximately 60 degrees latitude gets broken again when a front forms as cold polar air forces underneath warmer tropical air .These tropopause breaks are areas where two jet streams form in each hemisphere: the Polar Jet Stream, and the Subtropical Jet stream. A cross section of just the Northern Hemisphere is shown in Figure 39.

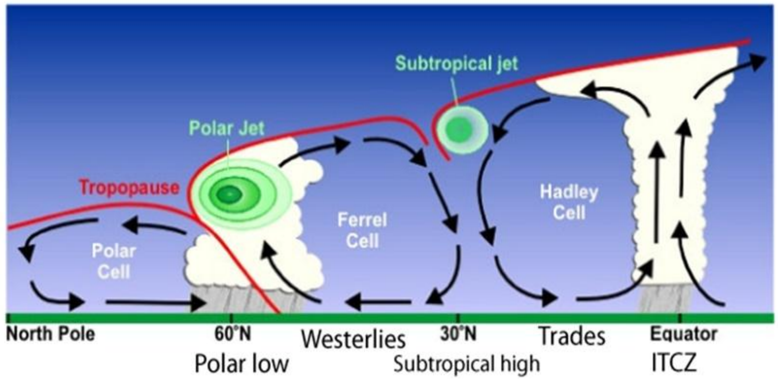


FIGURE 39 – Jet Streams and the Tropopause in the Northern Hemisphere

Figure 39 shows the breaks in the tropopause, and the location of the two jet streams in each hemisphere. There are three rotary vertical air circulations, known as the Polar, Ferrel, and Hadley cells which are important energy transport mechanisms for the earth. The Intertropical Convergence Zone (ITCZ) is the starting point for these mechanisms, and its position moves with the seasons, as shown in Figure 40. Moist, warm air gets drawn in on both sides of the ITCZ, where it then rises into the edge of the Hadley Cells. The rising moist air creates many thunderstorms in this area. Recent findings have supported an unproven theory that there are actually two parallel ITC regions.

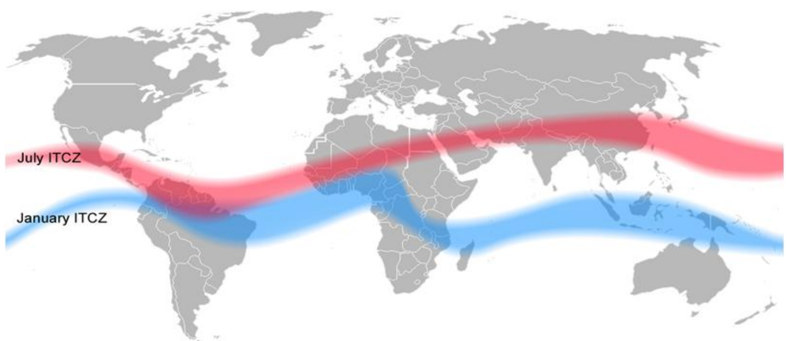


FIGURE 40 – Average ITCZ Locations For July (Red) and January (Blue)

Tropical storms commonly start their lives in the ITCZ. Figure 41 is a composite of the tracks of hurricanes and typhoons over the past 150 years, and it will be noted that the ITCZ is the birth place of most of them.

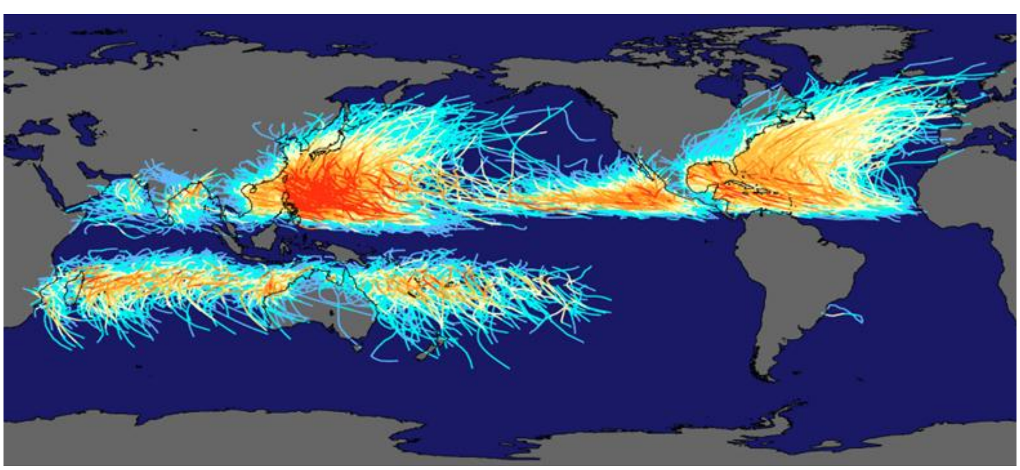


FIGURE 41 – 150 Years of Typhoons and Hurricanes

The jet streams (two in each hemisphere) also move throughout the year. Figure 42 shows the average positions of these jets.

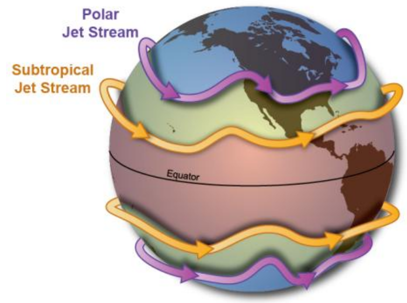


FIGURE 42 – Average Location of the Jet Streams

As discussed in the previous section, there is a general energy surplus in the equatorial regions, and a deficit nearer to the poles. This imbalance drives the flow of energy from the equator toward the poles by both the ocean currents, and the air currents that we have just reviewed.

ATMOSPHERIC LAYERS

As discussed earlier, all of earth's weather occurs in the troposphere, which is a well-mixed layer closest to the earth The troposphere is bounded to the top by the tropopause. The many atmospheric layers above the tropopause are primarily stratified, and are identified as shown in Figure 43.

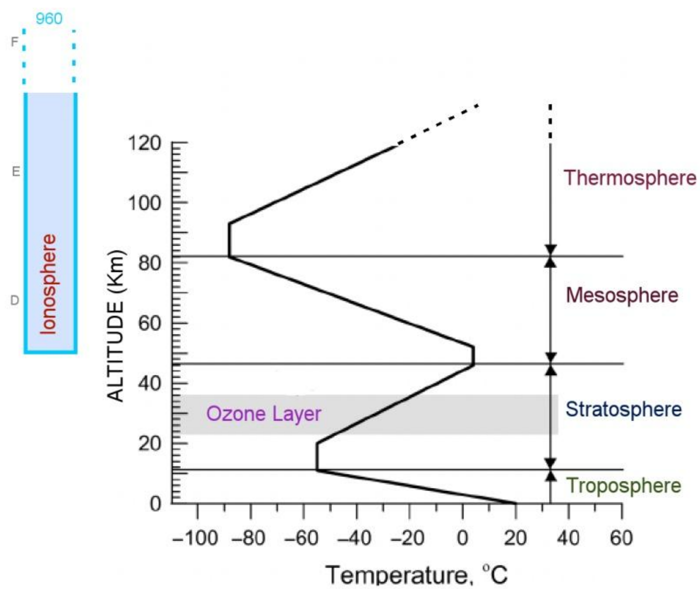


FIGURE 43 – Layers Of The Atmosphere

Looking at Figure 43, the temperature decreases linearly with altitude in the troposphere, with an average lapse rate of about -9.8 °C/Km. Just above the tropopause is an inversion layer, and then the temperature increases with altitude to the top of the stratosphere, where there is another inversion as the mesosphere is entered. Temperature again decreases with altitude through the mesosphere until another inversion layer is encountered at the start of the thermosphere, which extends up to about 690 Km. Beyond the Thermosphere is a region known as the exosphere.

As a side note, the term "Space" is defined as any altitude above 100 Km. The various companies offering brave (and rich) adventurers a ride into Space, all carry their passengers to an altitude of at least 100 Km before returning them to earth.

The ionosphere (shown on the left of Figure 43) is a region that contains ionized atoms and molecules. Energy from extreme ultraviolet solar radiation (wavelength of less than 121 nm) causes electrons to be "stripped off" the air's atoms and molecules, and the resulting electrically charged particles have properties that strongly affect long distance radio communication. There are several defined layers of ionization: D-layer (48 to 90 km), E-layer (90 to 150 Km), and F-layer (150 to 500 Km or more). These layers change significantly as the earth rotates through a solar day, and are also strongly affected by the 11 year solar sunspot cycle.

There is an ozone layer immediately above the tropopause inversion layer (TIL). In this region, solar extreme ultraviolet radiation dissociates atmospheric oxygen (O_2) into ozone (O_3). As noted earlier, ozone is a powerful greenhouse gas. The concentration of atmospheric ozone decreased by about 3 percent between 1979 and 2014, as the result of increased use of chlorofluorocarbons (CFCs). An agreement known as the "Montreal Protocol" in 1987 placed limits on the production and use of CFCs, and the atmospheric ozone concentration is slowly building back up. Ozone has no effect on UV-A (315 to 400 nm), but it mostly absorbs UV-B (280 to 315 nm), and completely absorbs UV-C (100-280 nm).

The tropopause inversion layer (TIL) is a direct result of the ozone layer absorbing UV solar energy. The TIL creates a "cap" to the normal adiabatic heat loss in the lower atmosphere. Ozone changes have had little effect on global warming, but they have affected global circulation, and it is believed that the polar vortex conditions have strengthened as a result.

As described earlier, although the total energy output of the sun has only minor variations over the 11 year sunspot cycle, the spectral distribution <u>does</u> change, and the ultraviolet component has significant variations. While the UV-A, B, and C components might vary by up to +/- 15%, the extreme UV wavelengths of less than 65 nm can vary by up to a factor of 7 through a complete sunspot cycle.

CLOUDS

Clouds are visible accumulations of small water droplets or ice crystals that are suspended in the atmosphere. They are categorized by their appearance and altitude, as shown in Figure 44.

FIGURE 44 – Cloud Types

Cumulonimbus clouds are easily spotted, because they have a great deal of vertical development, and can extend upwards right to the tropopause. They are associated with strong vertical air currents, turbulence, and precipitation.

Clouds are important, because climate is affected by “shading” due to the albedo changes of their top surface, and absorption of infrared energy being transmitted upward from the earth’s surface. Both of these parameters are difficult to predict. As an example, the range of albedo estimates for cirrus clouds is 0.1 to 0.3, for altostratus it is 0.2 to 0.5, for cumulonimbus it is 0.7 to 0.9, and for stratus it is 0.3 to 0.6. Unfortunately, no reliable proxies exist to study cloud cover’s influence on historical climate.

Clouds form when water vapour condenses because the air is saturated, and cannot hold any more moisture in gaseous form. The water vapour condenses on “condensation nuclei”[21], which can be dust particles, soot, aerosols, bacteria, or even phytoplankton. These nuclei are very small particles, usually 0.2 microns in diameter or less. The actual condensed water or ice droplet is about 100 times larger in diameter. Studies at CERN have shown that the rate of condensation about certain nuclei is strongly affected by cosmic rays coming from outer space. The incoming cosmic flux density is affected by changes to the protective heliosphere caused by sun’s changing magnetic field. It has been found that there is an inverse relationship between the cosmic ray flux and solar activity. Studies have shown that there might be an increase of 3 to 4 percent in cloud cover between solar maximum and solar minimum. This field is subject to ongoing research, and the actual mechanisms involved are not well understood.

High altitude bacteria have also been found to act as condensation nuclei. A number of factors can affect the population density of these bacteria, and hence the formation of clouds, and their subsequent effect on global temperature.

There are many theories about possible causes of global temperature change. One of the more interesting theories focuses on the fact that the earth's magnetic poles are moving, and the magnetic field strength is weakening prior to an expected "flip" in the earth's magnetism within the next century. These changes have happened many times before, at a rate of about once every 100,000 to 1,000,000 years. The last "flip" of the poles occurred about 780,000 years ago.[22] The decreasing magnetic field strength of the earth reduces the effectiveness of the earth's magnetosphere, thereby offering lesser protection to the incoming solar wind, and this will definitely affect the earth's atmosphere. Cosmic particles that reach the atmosphere have a part to play in the "seeding" of clouds, and cloud cover has a strong effect on the amount of the sun's solar radiation that actually reaches the earth's surface.[23]

VOLCANOES & FOREST FIRES

Volcanoes have the ability to affect the earth’s climate. Not only do they emit large amounts of greenhouse gases, but the fine particulate matter that is emitted into the atmosphere can cause “shading”, and SO_2 discharges can combine with water vapour to form sulphuric acid (H_2SO_4) that condenses into sulphate aerosols that can reflect incoming solar radiation. The emissions from volcanoes can reach all the way up into the stratosphere. Even underwater volcanoes can affect climate to some degree. It is estimated that about 75% of active volcanoes occur under water.

Wildfires and forest fires are often in the news. These fires not only create particulate matter, but they also release CO_2 which was previously stored (in a solid form) in the biomass. Vegetation is just one state in the Carbon Cycle that was discussed earlier, but its combustion often creates newsworthy events, and the media looks to “Climate Change” as being the culprit.

FEEDBACKS

The earth's climate system contains many feedback mechanisms – some are positive, increasing the temperature effect of small perturbations, and some are negative.

As a simple example of a positive feedback, consider what would happen if the global temperature increase by one or two degrees. Over a long period of time, this temperature increase would cause some of the ice caps to melt on Greenland and Antarctica, and the exposed ground which was previously covered with highly reflective ice (high albedo) would lower the average albedo of the surface, thereby absorbing more solar energy and causing more heating. Conversely, if the earth were to cool, the increased ice cover would increase the average surface albedo, and less solar energy would be absorbed, thereby causing additional cooling.

As an example of a negative feedback path, consider what might happen if the global temperature were to increase. This would result in the atmosphere containing more water vapour, which would ultimately result in an increase in cloud cover. The "shading" effect of the increased cloud cover would then reduce the solar energy arriving at the earth's surface, and there would be a net cooling effect.

As an example of a negative feedback mechanism, consider that an increase in atmospheric CO_2 will result in enhanced growth in trees and similar vegetation. This will then lead to an increased rate of removal of CO_2 from the atmosphere due to photosynthesis, thereby reducing the effect of the initial perturbation.

If positive feedback paths dominate and become excessive, it is possible that an initial perturbation will get magnified into a much larger change that continues to grow unabated. This form of excessive positive feedback is similar to that produced by a PA sound system when the system's gain is set too high, and the system breaks into a loud "howling" oscillation. In looking at the very long term temperature record, it is probable that this condition was encountered many times before over the millennia, and resulted in both high and low temperature extremes.

There are many different climate feedback loops in operation. Negative feedback tends to stabilize the climate, and reduce temperature excursions. Positive feedback can magnify the oscillations of global temperature caused by other effects. This is somewhat analogous to electronic amplifier design – negative feedback is commonly used to decrease distortion, while positive feedback can cause a non-linear response, and ultimately (if there is too much) result in oscillations.

There is controversy over the magnitude and effectiveness of the multiple feedback paths (positive and negative) which affect the earth's climate, and whether any of them might ultimately lead to a "tipping point", whereby the temperature starts to climb or descend in an uncontrollable fashion. The oceans have a major effect on all of this, and are the subject of a great deal of ongoing research.

CLIMATE MODELS

A number of attempts have been made to develop a scientific "model" of the various processes that can affect the earth's climate, so that predictions can be made for the future climate on the basis of known information. The IPCC has encouraged the development of many different models over the years, but they keep changing them as new information or theories are unearthed. Back in the 1970's, climate models were actually predicting a global cooling period, and concerns were expressed about the "coming ice age"!

In order to truly believe a computer climate model, it must be possible to put historical data into it, and then examine predictions to see if they match what actually occurred. It must also be possible to "run the model backwards" (in other words, we need "backsight" as well as "foresight"), and see if it can predict the historical ice ages and warm periods. So far, there is no model that can do this!

A climate change model needs to include the effects of the various complex interactions between the atmosphere, biosphere, and hydrosphere. Looking very simplistically at just the flow of energy from the sun to the earth, the model needs to account for the various absorption and reflection mechanisms (all at different wavelengths) that are applicable, and then come up with a net "energy budget" that can be used to predict the earth's surface temperature. Although numerical estimates exist for most of these mechanisms, there are non-trivial uncertainties in all of these numbers. When the entire budget is summed up, the resultant total cumulative uncertainties mask much of the residual effect that the model is trying to quantify! Further complicating all this is the presence of many different "feedback mechanisms" (some positive, some negative) that can exacerbate or diminish the effect of certain parameter changes.

Many climate models have been developed, as researchers strive to include all the possible factors affecting climate. Figure 45 charts the global temperature predictions for the tropical mid-troposphere made by 102 different climate models, and also plots actual observed temperature observations.

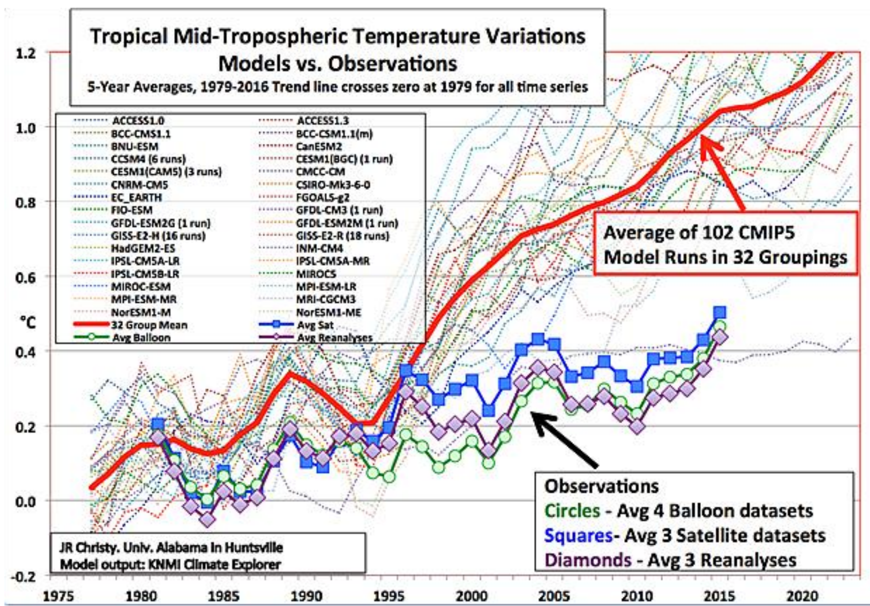


FIGURE 45 – Climate Model Performance

As illustrated by the above chart, the climate models that have been developed all tend to predict an increasing global temperature that is in excess of the observed actual temperature increases. Some of the fundamental problems with existing climate models is that they do a poor job of modelling cloud cover and the effect of the oceans (currents, energy storage, vertical circulation, etc).

The IPCC has emphatically stated: "*In climate research and modelling, we should recognize that we are dealing with a coupled, non-linear, chaotic system, and therefore that the long-term prediction of future climate states is not possible*" [24] (my emphasis). Data from climate models should be treated with a large degree of scepticism!

THE IPCC

The IPCC (Intergovernmental Panel on Climate Change) is a politicized technical organization that reviews and summarizes scientific papers related to climate change.[25] It does not do original research, nor does it conduct climate monitoring.

The IPCC was established in 1988 by the World Meteorological Association (WMO), and the United nations Environment Program (UNEP). It is specifically tasked with assessing published scientific information relevant to human-induced climate change.[26] In other words, the organization already believed that it was human activity that was causing climate change before they even started work!

Member are appointed to the IPCC by individual countries, presumably on the basis for their support of their country's adopted position on the topic. The IPCC generates "Assessment Reports" that are compilations of the technical material that has been reviewed. Six of these assessment reports have been produced so far. Before publication, wording of these assessment reports is reviewed on a line-by-line basis to ensure that the material is consistent with the position of each of the 195 countries that supplied members to the IPCC. Material that does not support the official consensus is often ignored or "de-bunked".

The IPCC relies heavily on computer models to predict future climate changes, and (as illustrated earlier) these always tend to overestimate future temperature rises. Although it has some scientific basis, the IPCC is heavily influenced by politics, and any conclusions or recommendations from the organization tend to have "hidden agendas"!

The IPCC and their political supporters do a good job of ignoring the paleoclimactic record, and focus only on very recent history, in the belief that the current (or recent) climate is ideal, and must somehow be maintained, despite historical records showing the futility of this dream. True to their initial charter, the IPCC continues to preach that climate changes are primarily a result of man's activities, and the associated generation of anthropogenic greenhouse gases. A series of global meetings known as COPs (Committee Of the Parties) have been held where political leaders can tout their countries' programs to reduce the emission of greenhouse gases, thereby supposedly reducing the rate of any future climate change. The politicians are cheered on by various "Green" organizations whose unwritten objective appears to be de-industrialization of the Western world and the destruction of Capitalism. The COP consensus is that any future global temperature rise must be limited to 1.5°C, and that this apparently requires that worldwide CO_2 emissions from anthropogenic activities be reduced to "Net Zero" by 2050.

NET ZERO

As mentioned above, many governments have decided to pursue the goal of becoming "Net Zero" by 2050 (or possibly later). This means that they want all CO_2 emitted by man's activities either to be eliminated or somehow compensated for by 2050 in the belief that this will slow the current rise in global temperatures, and limit the rise to 1.5°C above pre-industrial levels.

As discussed in previous sections, CO_2 concentration is not the primary driver of global temperature, and indeed, rising CO_2 levels might actually be a **result** of warming due to entirely natural factors. Despite the dubious scientific justification, politicians and special-interest groups have embraced the "Net Zero" battle cry, and are falling over themselves with announcements, proclamations, and protests as they attempt to destroy the world's economy.

The concept of Net Zero is that any continuing emissions of CO_2 need to be "offset" by actions to remove the same amount of CO_2 from the atmosphere. These "offsets" could be the planting of trees that absorb CO_2, or they could involve operating actual equipment that removes CO_2 from the atmosphere, and then sequesters it in a safe storage facility (this is called CCS, which stands for Carbon Capture and Sequestration). A marketplace has now developed whereby "carbon credits" are bought and sold, and some rather flimsy schemes have been created.

As an example of how ludicrous this churning process is, consider the example of the DRAX power plant that is located in the U.K. This power plant was built in 1974, and burned coal to generate electricity (in a conventional steam turbine system). Starting in 2013, this power plant was converted to burn compressed wood pellets. The pellets are manufactured in Canada, and shipped to the UK from the port of Prince Rupert, BC. The pellets were originally supposed to use scrap wood left over from existing logging operations, but demand eventually required that trees be specifically grown to feed the process. It was claimed that the entire process (*growing trees, converting the wood to pellets, transporting them between continents, and then burning them in a thermal power plant*) was "sustainable", because new trees were planted to replace those that were cut down!

DIRECT CARBON CAPTURE (DCC)

There are several companies developing technology and equipment for actually extracting ("capturing") CO_2 from the air. The CO_2 is then stored ("sequestered") either as a gas, or converted to some other form. The justification for doing this is that governments and agencies mistakenly believe that CO_2 emissions from human activities is causing the world to warm, and that not only must these emissions stop, but some of the CO_2 must be removed in order to lower the concentration in the atmosphere, thereby supposedly preventing future temperature rises. The processes used for DCC are complex, and require large amounts of energy to operate. It is claimed that the energy will come from "sustainable" sources (hydro, solar, wind, nuclear), so the whole process will help a country reach the goal of "net zero". Funding for these projects effectively comes from selling "carbon credits", because governments have inadvisably placed a dollar value on CO_2.

If these proposed projects go ahead, the scale and costs involved will be enormous. And remember, lowering the CO_2 concentration in the atmosphere by 1 ppm will only potentially reduce the temperature by between 9 and 15 thousandths of a degree C!

ENERGY & TRANSPORTATION

As part of the charge toward the Holy Grail of "Net Zero", the entire transportation infrastructure is being forced to dispense with the burning of fossil fuels. Governments apply so-called "Carbon Taxes" on the sale of hydrocarbon fuels, and the tax rates are methodically being increased as time goes by, in an effort to get users to switch to another type of energy.

Oil has been a major energy source for over two centuries. It has a high energy density (ie: a small and light weight amount of the substance has the potential to create a large amount of energy). A few decades ago, there was worldwide concern that we were running out of these fuels and only had a limited supply, but new exploration/extraction techniques, combined with more efficient energy use have allayed those concerns.

Fossil fuels are converted to energy by the process of combustion. Almost 40% of the material's potential energy is extracted in modern gasoline or diesel engines, and almost 55% in modern combined-cycle gas-fired power plants. The remaining energy is turned into waste heat. In building heating applications, the fossil fuel is burned to directly create heat: this process can have efficiencies of over 95%. All of these combustion processes generate CO_2, and this is the main focus of politicians, scientists, and environmentalists, despite evidence (as outlined earlier) that climate change is not being primarily driven by increases in CO_2 concentration.

Electricity is a good way of moving energy between terrestrial locations. Thermal power plants convert fossil fuels (usually natural gas or coal) to mechanical energy that drives efficient generators, and the resulting electricity can travel long distances over power lines to operate motors, heaters, lights, and industrial processes in remote locations.

Hydro-electric power plants are an environment-friendly way to generate electricity. After a major capital outlay, the plant produces electricity quietly and efficiently over a long period of time, without emitting greenhouse gases. Unfortunately, suitable sites for new hydro-electric plants are becoming scarce.

Nuclear power plants are pollution-free ways of reliably producing electricity at low cost (other than the very large initial capital outlay), but there are disposal issues with the spent fuel, and certain segments of the public are vehemently "anti-nuclear" based on political views or supposed safety concerns. Despite these concerns, nuclear power plants are widely used in some parts of the world (Over 70% of France's electricity is produced by nuclear power plants). The emerging technology of Small Modular Reactors (SMRs) has the potential to increase the penetration and acceptance of nuclear power, as mass-production techniques reduce the cost and size of efficient power plants designed to be distributed closer to the users.

Photo-voltaic cells ("solar cells") can produce electricity directly from the solar energy incident on the earth. The efficiency of the conversion process can be as high as almost 25%, but it degrades somewhat as the cells age. The biggest problem is that this is an intermittent source: it only produces electricity during the day time, and is affected by local weather conditions (clouds, fog, rain, etc).

Wind turbines produce electricity at any time of day **if** the wind is blowing, but their large, highly-visible profile means that they are usually located in remote areas or offshore. Other so-called "sustainable energy sources" include waves, tidal power, and geothermal.

Wind turbines and solar cells have received most of the publicity in recent years as large arrays of these devices have been installed around the world. The biggest problem is the intermittent nature of their output. To compensate for this, excess generating capacity has to be installed, and very large energy storage devices (batteries, pumped water, etc) have to be included to ensure a reliable source of supply.

If electricity is produced by techniques (such as hydro, solar, wind, or nuclear) that do not emit any greenhouse gases, there is strong political motivation to convert existing consumers of fossil fuels to use electricity as their energy source. Transportation has been a major user of fossil fuels, and the sector is highly visible to the public, so there is considerable pressure to electrify it.

Fossil fuels are an ideal way to power mobile devices (especially road vehicles, aircraft, and ships): the energy density (KW-h per Kg) is very high, and it is easy to quickly refuel as required. There has been much development in electrical technology for road vehicles, but the major problem has been the availability of electrical energy storage devices (primarily batteries) that are small and light enough to fit into the vehicle, and that have sufficient capacity to provide decent range between charges. The energy density (KW-h per Kg) of modern Li-ion batteries is about 2% that of gasoline or diesel fuel. Some electric cars have met with market success, but battery technology needs to develop a major increase in battery energy density before they are considered viable for mainstream applications, and then the problem will be one of installing enough charging infrastructure to allow for unimpeded travel without the drivers suffering from "range anxiety".

Ships, highway trucks and airliners pose their own problems, and are unlikely to be weaned off of fossil fuels for some time to come. These applications need energy storage devices that have much higher density (both by volume and by weight) than batteries – the use of hydrogen (produced by electrolysis of water) and fuel cells is being vigorously pursued. Hydrogen can also be burned directly in modified jet engines or even reciprocating engines, but hydrogen has storage issues that need to be addressed. Hydrogen's energy density (KW-h per Kg) is quite high, but it occupies a large volume, so must be stored at very high pressures if storage tanks are to be kept to a reasonable size. Hydrogen can also be stored in a liquid form, but the extremely low cryogenic temperatures required (-253°C) present significant challenges.

If it were possible to convert all power generation, heating, and transportation applications to non-fossil fuel technology,[27] it would be possible to reduce the total amount of man-made CO_2 emissions by over 50%, but this would have a negligible effect on global temperature. It would of course still be required to extract oil and natural gas from the ground for the manufacture of synthetic materials, plastics, asphalt, lubricants, and pharmaceuticals.

CONSENSUS

In the popular press that reports on climate change, it is common to hear terms such as "The science is settled", or "97% of scientists agree". However, consensus is not a legitimate way to conduct science! If we allowed mere consensus to dictate scientific beliefs, we would still think that the earth was flat and the sun revolved around it, because Pythagorus, Socrates, Aristotle, and Galileo were not part of the "the scientific consensus" at the time.

The "97% of scientists" are often talked about in the media, but there is some doubt about the validity of this number,[28] [29] [30], or their conviction[31] and they fail to mention the numerous other respected scientists who do not believe that CO_2 emissions from man's activities have a meaningful effect on the earth's climate. Organizations such as Clintel [32] are composed of experts from academia (including Nobel laureates) and industry who dispute much of the work that has been done by the IPCC.

The IPCC scientists have had a number of scandals where it has been alleged that data was falsified in order to support the pre-ordained conclusions that were mandated to be produced. Examples include Mann's famous "Hockey Stick",[33] and the scandal at East Anglia University when leaked e-mails revealed that data was being systematically manipulated.[34] [35] It is claimed that the "East Anglia Data Manipulation" has now been satisfactorily explained, but there is still controversy surrounding the incident. There is considerable controversy and emotion surrounding the topic of "climate change", and both sides of the argument have resorted to less than professional tactics.[36]

Take everything with a grain of salt, and "follow the money". Ever since Al Gore (a former US politician) rejuvenated his career by producing a glossy, sensational, but wildly inaccurate and misleading documentary entitled "An Inconvenient Truth", politicians have been scrambling to climb on the bandwagon and hitch their stars to the climate/environmental movement. Meanwhile, universities, researchers, consultants and NGO's have been given easy access to funds for projects which will support the IPCC's "consensus viewpoint" that Global Warming is caused by man's activities, and that it is bad for humanity. Left-leaning organizations are seizing on "climate change hysteria" as further evidence of capitalism's evil nature.

Unfortunately, Canada's school system has embraced the IPCC's position wholeheartedly, and is indoctrinating our children with their potentially incorrect conclusions, and teaching that "consensus" is now apparently a legitimate way to conduct scientific research. Al Gore's fear-mongering (but inaccurate) documentary is also being widely shown in the schools. throughout the world.

Meanwhile, anyone who offers dissenting points of view is mercilessly hounded and deprived of funding. Climate warming is turning into a religion! [37] Heretics are labelled as "deniers", or "sceptics", and are blacklisted.

Internet resources such as search engines, video repositories, and social media have all been programmed to emphasize the "consensus opinion", and downplay, black list, or counter-label viewpoints or questions from individuals who question the so-called "science".

And of course, don't believe anything you read in the popular press as they seek to retain or expand readership by printing more and more sensational headlines such as: "Highest Temperature Ever Recorded", "Global Warming Increasing Hurricane Threat", "The Glaciers Are Melting", "Unprecedented Warming", "Climate Change Is Destroying Fish Stocks", "Global Warming Is Worse Than Predicted", "Polar Bears At Risk", and "The World is Boiling".

CORRECTIVE ACTION

As discussed above, the predominant factors affecting future climate on the earth are natural; humans can do little about this unless large-scale (and very controversial) geoengineering efforts [38] are made to force climate change artificially (such as by putting reflective particles into orbit around the earth, thereby reducing the incoming solar flux).

However, throughout history, man has shown a remarkable ability to adapt to external events. As an example, the Netherlands has even adapted to having 25% of its surface area being beneath sea level by constructing dykes and flood control dams. London has adapted by building the Thames Barrier to protect the city from abnormally high sea levels under certain conditions.

Note that there is a difference in temperature trends between the Northern and Southern hemispheres. As an example, Figure 44 presents a graphical record of polar sea ice extent [39] over a 30 year period; it can be seen that the Arctic ice is shrinking at the same time that Antarctic ice is slightly expanding:

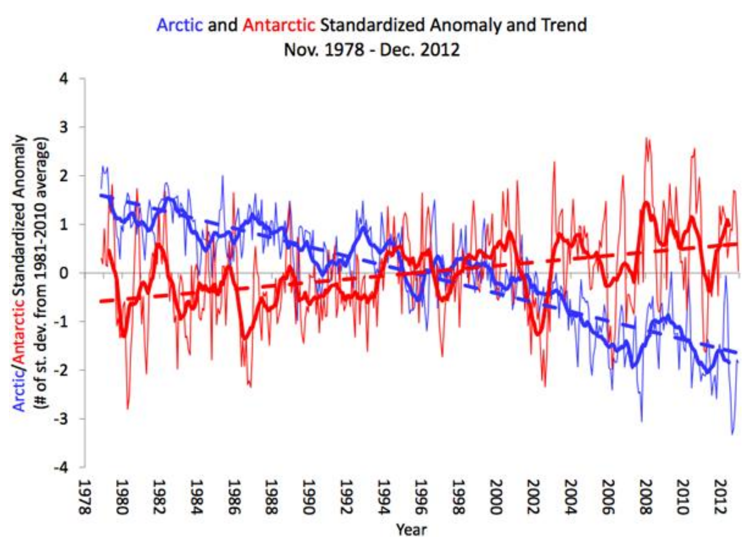


FIGURE 44 – Polar Sea Ice Extent

If the earth warms up, there will be a general shift of the population to cooler regions of the planet. There have been many climate-induced population migrations in the past.

Humans tend to abhor change. A lot of people like things "just the way they are now", and believe that the climate we have been enjoying for the past few decades is "perfect" for them. But it is the height of arrogance and selfishness to believe that present conditions are ideal for <u>us</u>, and that we have the ability to control the climate so that it stays this way! The best recommendation that can be given is that man must learn to <u>adapt</u> to the continually changing climate.

<u>SUMMARY & CONCLUSIONS</u>

The material reviewed so far in this paper confirms that there are a large number of factors that affect the earth's climate. Many of these are poorly understood by man, and there are some factors that probably haven't even been discovered yet.

A number of conclusions can be taken away from the information presented so far in this document:

a) *Climate change is a naturally-occurring, cyclic phenomena, and it has been going on for millions of years.*

b) *Climate change is primarily driven by changes in the energy of the sun that impinges on the earth. The dominant factors driving this are variations in the sun (total output power, spectral distribution, sunspot cycles) Milankovitch Cycles, variations in ocean currents (ENSO, PDO, and AMO). Other factors include the effect of varying cosmic particle influx and high altitude bacteria, causing changes in cloud cover.*

c) *The primary greenhouse gas is water vapour. The effect of atmospheric CO_2 on global temperature change is much less. Because of the non-linear effect of CO_2 concentration, increases beyond the current level will have a decreasing effect on the earth's climate.*

d) *Man-made CO_2 does have a <u>minor</u> effect on global temperature changes, but it is not the dominant factor. A reduction of man-made CO_2 emissions would have a negligible effect on global temperature.*

e) *Man's understanding of the various climate-influencing factors is very limited.*

f) *Climate models are not effective at forecasting future long-term global temperatures.*

g) *There is very little that mankind can do to affect global temperature change. It does not make sense to introduce regulations that will have a negative impact on Western economies in a pointless attempt to change the natural rate of global climate change.*

h) *Mankind will have to learn to **<u>adapt</u>** to future climate changes. If mankind is still around in a few thousand years, they will then have to adapt to global cooling and glaciations!*

Any legislative efforts to limit man-made carbon dioxide emissions at the local, regional, provincial, or federal levels may be well-intended, but are ultimately futile, and potentially dangerous. These efforts will harm the economy, waste resources, and not significantly affect the naturally-occurring cyclic climatic changes.

APPENDIX A

Unit Prefixes and Abbreviations

Prefix	Multiplier	Abbreviation
Exa	10^{18}	E
Peta	10^{15}	P
Tera	10^{12}	T
Giga	10^{9}	G
Mega	10^{6}	M
Kilo	10^{3}	K
Centi	10^{-2}	c
Milli	10^{-3}	m
Micro	10^{-6}	µ
Nano	10^{-9}	n
Pico	10^{-12}	p
Femto	10^{-15}	f

APPENDIX B

USEFUL DATA

Here are some numbers that might prove useful in analyzing proposals related to measuring or attempting to control the earth's climate:

Total mass of atmosphere:	5.1×10^{18} Kg, or 5.1×10^{15} tonnes
Mass of CO_2 in atmosphere:	3.2×10^{12} tonnes (*at 415 ppmv, the concentration in mid-2023*)
Mass of 1 ppmv of atmospheric CO_2:	7.8×10^{9} tonnes, or 7.8 Gigatonnes

Mass (in Gigatonnes) of anthropogenic CO_2 emissions in 2021 by country[40 41]*:*

China	12.4 Gt
USA	4.7 Gt
EU	2.8 Gt
India	2.7 Gt
Russia	1.9 Gt
Japan	1.1 Gt
Iran	0.7 Gt
Germany	0.7 Gt
South Korea	0.6 Gt
Indonesia	0.6 Gt
Saudi Arabia	0.6 Gt
Canada	0.6 Gt
TOTAL WORLD	37.8 Gt

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