The Physics of Global Warming

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Key Points:

- Electromagnetic radiation travels as a broad spectrum of frequencies, not as waves, nor particles.
- Energy of electromagnetic radiation is the Planck constant times frequency, which is not additive.
- There is not enough heat absorbed by greenhouse gases to play a major role in global warming.

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Abstract

Temperature at the stratopause, 50 km above Earth, is maintained ~50^{o}C warmer than temperature at the tropopause, 7 to 20 km above Earth, primarily by ultraviolet-C solar radiation dissociating oxygen, which makes up 21% of Earth’s atmosphere. Dissociation turns bond energy efficiently into atmospheric temperature by causing molecular pieces to fly apart at high velocity. Gas temperature is proportional to the average velocity of all gas molecules squared. Absorption of infrared radiation, however, by carbon dioxide, making up only 0.04% of the atmosphere, has yet to be shown experimentally to actually warm air the 0.7^{o}C observed globally since 1945.

The ozone layer, primarily 15 to 30 km above Earth, normally absorbs most ultraviolet-B solar radiation energetic enough to dissociate ozone, keeping the lower stratosphere warm. When total column ozone is depleted, more ultraviolet-B radiation is observed to reach Earth, cooling the lower stratosphere and warming Earth. This radiation dissociates ground-level ozone pollution, warming near surface temperatures, and penetrates tens of meters into oceans causing observed increases in ocean heat content.

By the late 1960s, major increases in the manufacture of chlorofluorocarbon gases (CFCs) led to an increase in global warming. The Montreal Protocol, effective in 1989, mandated major cutbacks in CFC production. By 1993, increases in CFCs stopped. By 1995, increases in ozone depletion stopped. By 1998, increases in global temperatures stopped. Ozone is also depleted by effusive basaltic volcanic eruptions, the largest of which since 1783 occurred in 2014-2015 causing global temperatures to rise sharply again.

1 Introduction

The hottest year since thermometers were invented was 2015 and 2016 is likely to be even hotter [*HadCRUT4*, 2016]. The world warmed 0.7^{o}C since 1945. Did man cause this warming or are we just coming out of the Little Ice Age, which reached its last minimum temperature in 1850? What can we do about it? What should we do about it?

According to the Intergovernmental Panel on Climate Change (IPCC) “human influence on the climate system is clear, and recent anthropogenic emissions of greenhouse gases are the highest in history. Recent climate changes have had widespread impacts on human and natural systems. … Continued emission of greenhouse gases will cause further warming and long-lasting changes in all components of the climate system, increasing the likelihood of severe, pervasive and irreversible impacts for people and ecosystems. Limiting climate change would require substantial and sustained reductions in greenhouse gas emissions which, together with adaptation, can limit climate change risks" [*IPCC*, 2014]. This broad consensus led to the Paris Agreement on December 12, 2015, where representatives from 195 countries agreed that climate change is a major problem and that all countries must work together to reduce greenhouse-gas emissions.

Greenhouse warming theory is based quantitatively on the assumption by *James Clerk Maxwell* [1865] that electromagnetic radiation (EMR) travels through air and space as waves. Thinking in terms of waves, the amount of energy is proportional to the square of the wave amplitude, the amount of energy can be determined by integrating across bandwidth, and the total amount of energy is the sum of all appropriate radiative forcings. In this paper, we will explore the history of how EMR travels and show that the interaction of electric and magnetic fields makes it possible for thermal oscillations on the surface of radiating matter to resonate with molecules of gas and other absorbing matter, transferring heat. In this case, the level of energy (E) equals the Planck constant (h) times frequency of oscillation (ν) of frictionless atomic oscillators ($E=h\nu$) and levels of energy cannot be added together because it makes no physical sense to add frequencies (colors) of light (EMR). All frequencies are observed to coexist in air and space without interacting in any way except when in the immediate presence of matter. The intensity, brightness, or amplitude of oscillation at each frequency is determined by the temperature of the radiating body and decreases with the square of the distance traveled, and decreases due to absorption by intervening gas molecules.

Understanding $E=h\nu$, explains the structure of Earth's atmosphere and why increased ultraviolet-B radiation reaching Earth's surface when ozone is depleted is 48 times more energetic, 48 times "hotter" than infrared radiation absorbed most strongly by carbon dioxide. The more energetic the radiant energy, the higher the frequency of oscillation, the more heat can flow and the higher the temperature will be to which the absorbing body can be raised. Ozone depletion caused by manufactured chlorofluorocarbon gases (CFCs) explains global warming from 1970 to 1998 far more clearly, directly, and completely than observed changes in greenhouse gases. Ozone depletion caused by the eruption of Bárðarbunga volcano in Iceland in 2014-2015, the highest rate of effusive basaltic volcanic eruption since 1783, explains why temperatures have been rising rapidly since 2014. Throughout the history of Earth, major effusive eruptions of basalt are contemporaneous with major warming and mass extinction [*Ward*, 2016].

I have spent ten years of full-time effort in retirement trying to understand several enigmas related to global warming. Without deadlines and few other obligations, I have been able to take the time to question widespread assumptions, digging deeper wherever and whenever necessary. A few years ago, I began to realize that maybe we do not understand electromagnetic radiation as well as we think we do. Recognizing that light may simply be a broad spectrum of frequencies extends classical physics to the atomic level, grossly simplifying quantum mechanics and especially quantum electrodynamics—making many of the phenomena they describe deterministic and intuitive. Recognizing that the level of energy in light is simply frequency times the Planck constant, as is well understood by atmospheric chemists, helps us understand why current climate models are not calculating thermal energy properly. Recognizing that what Einstein called “spooky action at a distance” is simply a physical property of frequency, opens new vistas.

The purpose of this paper is to review the extensive evidence for why light appears to be a broad spectrum of frequencies of oscillation and the implications. If you find such questioning of fundamental aspects of our well-honed, scientific belief systems threatening, please step back, take a deep breath, relax, and read on thoughtfully. The journey is well worth the effort.

2. Does Light Propagate as Waves or as Particles?

Natural philosophers and physicists have debated for more than 2400 years whether visible light, or more generally electromagnetic radiation (EMR), travels through air and space as a wave or a particle. Around 400 BC, Democritus suggested light is a stream of solar atoms or particles. Aristotle, on the other hand, hypothesized that light propagates as a wave, a disturbance in a hypothetical element known as “aether”. By 1027 AD, the Arab polymath Ibn-al Haytham completed *The Book of Optics*, a seven-volume treatise describing reflection and refraction of light. He thought of light as traveling along straight, linear rays composed of particles.

Descartes [1633] described reflection and refraction by modeling wave-like disturbances in an aether. *Hooke* [1665] and *Huygens* [1678] developed the mathematics of light travelling as a wave through an enigmatic medium. *Newton* [1704], on the other hand, developed a corpuscular hypothesis for light as a stream of particles. He reasoned that only particles could travel along such straight lines, or rays, observed for light. *Fresnel* [1818] noticed that light could be polarized and concluded that light must, therefore, travel as transverse waves that oscillate perpendicularly to the direction of travel. He stressed that there must indeed be some form of luminiferous aether in space that somehow allows light to propagate.

Faraday [1849] introduced the concept of an electromagnetic field in air and space consisting of electric and magnetic waves oscillating in mutually perpendicular planes, with both planes being perpendicular to the direction of travel. *Maxwell* [1865] formulated a set of partial differential equations showing that electric and magnetic fields in space satisfy the wave equation when you think of electromagnetic radiation as transverse waves traveling at some velocity through some medium. For decades, physicists sought to discover what this medium, Fresnel's luminiferous aether, was or to prove that it could not exist. *Michelson and Morley* [1887] finally convinced most physicists that such an aether does not exist and therefore light cannot propagate through space as mechanical waves. Maxwell’s equations, however, became not only highly respected, but they have been used very successfully to design almost every piece of electronics that has been invented to date. They must, therefore, have some validity at least associated with matter. Physicists were left with no choice but to conclude that electromagnetic radiation is somehow different from waves in an aether.

Einstein [1905] proposed that light could travel as particles of energy, “light quanta”, ultimately known as photons [*Lewis*, 1926]. Einstein was trying to understand the photoelectric effect, where electrons are released from the surfaces of certain polished metals only when they are illuminated with high-enough frequency light, typically deep blue to ultraviolet. He may have reasoned that for a particle, an electron, to be given off, it might have been dislodged by another particle, a light quantum, although he did not express it precisely in this way. Since 1905, most physicists have adopted the concept of wave-particle duality, which *Einstein and Infeld* [1938] describe as follows: "But what is light really? Is it a wave or a shower of photons? There seems no likelihood for forming a consistent description of the phenomena of light by a choice of only one of the two languages. It seems as though we must use sometimes the one theory and sometimes the other, while at times we may use either. We are faced with a new kind of difficulty. We have two contradictory pictures of reality; separately neither of them fully explains the phenomena of light, but together they do."

From basic logic, if light is sort of like waves and sort of like particles, then light is not equal to either. A mule is sort of like a horse and sort of like a donkey, but is not equal to either—it is a mule. We see the effects of light, but we do not see light itself until it interacts with matter. Why is it that for more than 2400 years, we have been trying to describe something we cannot see in terms of things we can see—waves and particles? Basically because we seek to describe something new with terms that are familiar.

By 1791, experimenters began noticing that an electric spark causes "action at a distance"—a spark over here causes an effect over there with no apparent physical connection between them. Maxwell's equations showed that electromagnetic waves could, at least mathematically, travel through space as waves that we cannot see. Hertz, in the 1880s, demonstrated experimentally what he interpreted as Maxwell's waves related to sparks that emit high frequencies, and in the 1890s, Marconi began using these frequencies to develop wireless telegraphy and ultimately radio.

Radio is a clear example where a frequency is transmitted here and received over there without anything being observed happening in between. By tuning a radio receiver to resonate at the precise center frequency transmitted, a clear radio signal can be extracted from a continuum of frequencies shared with thousands of other radio signals and other frequencies of radiation. These frequencies travel line of sight from transmitter to receiver with no need to think in terms of waves except to explain how line of sight can be bent in the immediate presence of matter—how radio signals can be refracted around some topography. It is an interesting twist of fate that the unit of frequency, the Hertz, is named in honor of the person who demonstrated what he was thinking of as Maxwell's waves.

Wave theory defines frequency as velocity divided by wavelength. This is the frequency of a propagating wave where energy is proportional to the square of the amplitude of the wave that is deforming some medium. Frequency described in this paper, however, is the frequency of oscillation of a frictionless atomic oscillator where the level of energy is directly proportional to the frequency of oscillation. A frictionless oscillator does not propagate anywhere, but its frequency of oscillation propagates without change through air and space, even for galactic distances, because of the frictionless interaction of electric and magnetic fields.

In this paper, I describe abundant evidence suggesting that light is simply a broad spectrum of frequencies. We cannot see frequencies traveling in air or space, but we see the effects of frequencies when they cause molecular bonds in matter to resonate at those frequencies. The visible spectrum of colors is visible precisely because these are the resonant frequencies of cells in the cones of our eyes. Every shade of color is a precise frequency. Similarly, we hear sound when much lower frequencies cause much larger hairs of different lengths to resonate in the cochlea of our ears. Frequencies and resonance are two of the primary vital sensory links between our bodies and the physical world around us.

Physics is about the physical—what is physically happening. The ultimate goal of physics is to develop a physically intuitive understanding of Nature and ultimately to codify observations into equations that can explain and predict basic observations of physical things. As Richard Feynman stated, "a physical understanding is a completely unmathematical, imprecise, and inexact thing, but absolutely necessary for a physicist" [*Feynman et al.*, 1963b]. It takes good physical intuition to make the appropriate assumptions necessary to distill the physics down to meaningful mathematical equations. Once an equation is written, however, it is all too easy to forget about the physical assumptions made and simply proceed with the mathematics.

Einstein's concept from studying the photoelectric effect that energy at the atomic level is quantized and the heroic effort to explain EMR as waves, particles, or wave-particle duality, have led to quantum mechanics and quantum electrodynamics, which are brilliant mathematics and ingenious experimental designs that appear to explain reality with great precision, but do not make physically intuitive sense. Richard Feynman, who shared the Nobel Prize in Physics in 1965 for his fundamental work in quantum electrodynamics, exclaimed, "I think I can safely say that nobody understands quantum mechanics" [*Feynman*, 1965]. "The theory of quantum electrodynamics describes Nature as absurd from the point of view of common sense. And it agrees fully with experiment. So I hope you accept Nature as She is—absurd" [*Feynman et al.*, 1963a]. Max Planck and Albert Einstein, the fathers of quantum physics, never were comfortable with this conclusion.

3. Light Cannot Travel Through Space Just Like Mechanical Waves Travel Through Matter

From Aristotle, to Descartes, to Hooke, to Huygens, to Fresnel, to Maxwell, every discussion of light as waves is based on the concepts that waves are a physical property of matter, that waves, as they propagate, displace molecules of matter, and that the bonds or pressure holding matter together gradually return these molecules to their original position as the wave passes by. There is no matter in space, there are no bonds in space, there is no pressure in space, and we have been unable to identify a luminiferous aether in space. Seismic waves propagate at velocities of kilometers per second and these velocities increase with increasing density of matter. Light travels at velocities 22,000 times faster than the fastest seismic wave. Does it make physical sense that a luminiferous aether would have a density much greater than ordinary matter? Light simply cannot propagate in space in a manner similar to mechanical waves in matter.

A wave in matter can be approximated by a Fourier series, the sum of an infinite series of terms where each term is a function of a frequency times an amount. It is the bonds holding matter together that form the physical basis for the plus signs adding the terms together. Light, on the other hand, is observed in rainbows, when passing through prisms, and through spectral analysis, to contain many different frequencies (colors) that are not additive, that do not interact with each other in any way until in the immediate vicinity of matter. EMR is a Fourier series, therefore, where the plus signs are replaced by commas—all the frequencies from radio and television signals, to infrared, to visible light, to ultraviolet, to X-rays, to gamma rays coexist in air and space in varying amounts that differ by location and over time but do not interact with each other except sometimes in the immediate presence of matter.

EMR does display wavelike properties such as reflection, refraction, birefringence, and interference, but only when in the immediate presence of matter. These properties appear to be caused by the interaction of EMR with the bonds holding the surface of the matter together. We will need to revisit our textbook explanations for these common phenomena when we understand more clearly what light really is.

4. Light Does Not Appear to Travel Through Space As Particles

Planck [1900] postulated for EMR that energy (E) equals a constant (h) times frequency (ν, the Greek letter nu): $E=h\nu$. This simple equation became known as the Planck-Einstein relation and is typically thought of as the energy of a photon. Photochemists use $E=h\nu$ to specify the energy needed to dissociate a molecule of oxygen (O_2), for example, into two atoms of oxygen (O), traditionally written as:

$$O_2 + h\nu\ (\lambda < 242.4\ \text{nm}) \rightarrow 2O$$

where λ is wavelength that must be less than 242.4 nanometers for this reaction to take place. As shown in this paper, wavelength is not an accurate concept when referring to EMR in air and space. Therefore, it would be more consistent to write this equation all in terms of frequency (ν):

$$O_2 + h\nu\ (\nu > 1237\ \text{THz}) \rightarrow 2O$$

$E=h\nu$ is a deceptively simple equation that takes some time to understand well. As explained in more detail in the next section, $E=h\nu$ is the energy of oscillation of a frictionless atomic oscillator. $E=h\nu$ says that energy of oscillation is the same thing as frequency times a scaling constant h, now known as the Planck constant. Setting $\nu=1$, we see that h is the energy contained in a frequency of one cycle per second. The Planck constant (h) converts frequency of oscillation in the microscopic realm into joules in the macroscopic realm so that conservation of energy can be demonstrated between macroscopic and microscopic realms. In the macroscopic realm, a joule is defined as the energy transferred (or work done) to an object when a force of one newton acts on that object in the direction of its motion through a distance of one meter. This definition has no physical relationship to oscillatory energy. The Planck constant is thus a bridge from microscopic oscillatory energy to macroscopic translational energy, just as the Boltzmann constant is a bridge from microscopic gas molecules to macroscopic moles of a substance.

Macroscopic energy is typically additive, which means macroscopic energies can be added together, because macroscopic energy is a physical amount of energy, an extensive physical property dependent on the size or extent of the matter involved. Double the mass, you double the energy, for example, when evaluating macroscopic kinetic energy or macroscopic gravitational potential energy. At the microscopic level, however, where $E=h\nu$, energy is not an amount of energy, it is a level of energy, an intensive physical property that varies throughout the material at the microscopic level but does not vary with the size of the system. Intensive physical properties are well known not to be additive. Microscopic total energy E, therefore, cannot be equal to $h(\nu_r + \nu_g + \nu_b)$, for example, because it makes no physical sense to add frequencies together. If you add some red light to some green light, to some blue light, you do not get ultraviolet light. You simply get some red light, coexisting with some green light, coexisting with some blue light. For radiation, all frequencies coexist without interacting in any way in air or space unless in the immediate presence of matter.

Microscopic energy does not have an amount, it has a frequency, which is a level of energy ($E=h\nu$), and it has an amplitude of oscillation (intensity or brightness). The thermal effect of microscopic energy, how much heat will flow per unit time, is a function of dosage, 1) how long a piece of matter is exposed to some level of energy (frequency of oscillation), 2) what the difference in amplitude (difference in intensity) is between the radiation and the absorbing matter at each frequency, and 3) what the sensitivity of the matter is to that frequency. We are quite familiar with the concept of dosage when dealing with gamma rays (nuclear radiation), X-rays, and ultraviolet sunburning radiation.

A photon is defined in particle physics as an elementary particle, the quantum of EMR that carries electromagnetic force and has zero rest mass. The photon is central to the Standard Model of particle physics and is a very handy mathematical concept used widely in mathematical equations that have been developed and tuned to describe observations extremely well—but is the photon a physical thing?

Because physicists gave up on the need for quantum mechanics to be physically intuitive, many concepts have been developed that make good sense mathematically, but little sense physically. In most cases, the mathematics describes the quantitative result of an assumed interaction, not the actual physics of the interaction. This is why the mathematics appears to work so well.

If a photon is a real physical thing and E=hν is the energy of a photon, is there a different photon for every frequency? Frequency is a continuum and therefore energy is a continuum. What does a continuum of photons look like? Do the different photons interact? If not, why not? When a photon collides with a molecule of gas, explain physically how energy is actually transferred from the photon to the molecule. If the photon only glances off the molecule, how much energy is shared?

Spectral physicists have documented in great detail [*Rothman et al.*, 2013] that many molecules of gas absorb energy from the surrounding electromagnetic field only at frequencies that are the normal modes of oscillation of all the degrees of freedom of all the bonds holding the molecule together. In other words, the details of the energy absorbed are determined by the resonant properties of the absorbing molecule. Explain how photons would interact with a molecule to cause these well-observed spectral lines of absorption.

There are dozens of questions of this type, seeking to understand what photons are physically, that have never been answered. They have simply been avoided by agreeing that quantum mechanics does not need to make physical sense. Photons are an extremely useful mathematical concept that are used widely in equations to solve serious problems, but a photon does not make much physical sense and appears to be one of the reasons why quantum mechanics is so physically unintuitive. Many experiments in particle physics seek to study photons often through liberal use of photomultipliers based on the photoelectric effect. *Falkenburg* [2010] explains, in very thoughtful detail, how we tend to observe in the laboratory what we think we are looking for, not necessarily what is physical reality.

5. Thermal Energy Is a Broad Spectrum of Frequencies of Oscillation of Atomic Oscillators

The bonds that hold particles of matter together are not rigid. They can be modelled quite accurately by the Morse potential where the length of each bond oscillates in response to two opposing electrodynamic forces—one that attracts the particles when they are relatively far apart, and another that repels them when they are too close together. The term "electrodynamic" signifies invisible forces caused by differences in the electric charges that are bound to the particles, (i.e., that do not generate an electric current or an electric discharge moving away from the particles).

The amplitude of oscillation of a molecular bond increases with increasing thermal energy, which is directly proportional to increasing frequency of oscillation, E=h*v* (y-axis, Figure 1). This amplitude oscillates along the horizontal black line with arrowheads between a minimum value along the black line on the left, labeled "Repulsion," and a maximum value along the black line on the right, labeled "Attraction." The length of the bond and the amplitude of oscillation at every frequency also increase with increasing temperature shown by the red line. As the thermal energy (frequency of oscillation, *v*) increases, the amplitude of oscillation increases, and the horizontal black line in Figure 1 rises and lengthens, until the amplitude becomes so large at the energy threshold (E_{max}) that the bond comes apart, causing the constituent atoms or molecules to fly apart—to dissociate.

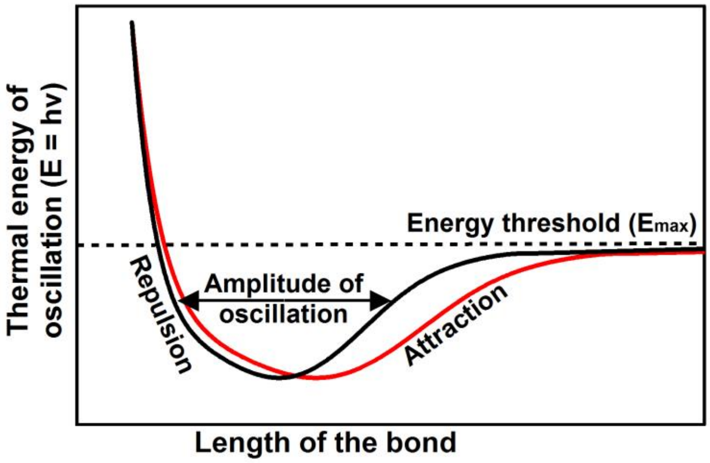

Figure 1. The length of each bond holding matter together oscillates between electrodynamic forces of repulsion on the left and electrodynamic forces of attraction on the right. When energy equals or is greater than the threshold energy (Emax) the bond comes apart. At a higher temperature, the length of the bond increases and the amplitude of oscillation at every frequency increases (red line).

Such electrodynamic oscillations are often compared to mechanical oscillations, such as a pendulum swinging back and forth. The longer the pendulum or the heavier the mass on the bottom of the pendulum, the lower the natural frequency of oscillation. There are at least two very important differences between mechanical oscillators and an electrodynamic atomic oscillator, however. As shown in Figure 1, electrodynamic oscillators are asymmetric, with longer amplitude of oscillation on the attraction side than on the repulsion side. This means that as thermal energy increases, the mean amplitude of oscillation, the mean length of the bond, increases, which means that the material expands. It is widely observed that most solids, liquids, and gases expand when heated.

The second difference is that the electrodynamic oscillator has no friction, so that it can oscillate with constant amplitude indefinitely. The only way to add or subtract energy from such a frictionless oscillator is by resonance with a nearby oscillator. Resonance occurs when two oscillators near each other are oscillating at similar frequencies but with different amplitudes of oscillation. The oscillator with the lower amplitude will absorb "amplitude" from the oscillator with the higher amplitude until they both have the same amplitude at the same frequency. Since amplitude of oscillation is a function of energy of oscillation, as shown in Figure 1, thermal energy is shared and equalized, and will reach thermal equilibrium primarily via resonance. Thermal equilibrium is the condition, also known as the state, in which thermal energy (heat) no longer flows spontaneously from one oscillator to another.

Resonance is all around us. It is the way we see and hear. Many examples of resonance are illustrated on YouTube, including sound breaking a wine glass oscillating at its resonant frequency, tuning forks exchanging energy, and standing waves in a pipe. Two dimensional examples include resonance in a membrane similar to the head of a drum, and waves on the surface of water.

Resonance is central to understanding the four laws of thermodynamics and how heat flows. The zeroth law of thermodynamics essentially defines temperature as "that which is equal when heat ceases to flow between systems in thermal contact" [*Grossman*, 2014], when amplitudes of oscillation at each frequency are equal. The first law of thermodynamics states that energy cannot be created nor destroyed but only converted from on form to another, when amplitudes of oscillation are not equal. The second law of thermodynamics essentially defines the arrow of time, that energy can only flow by resonance from higher amplitude of oscillation to lower amplitude of oscillation, from hot to cold. The third law of thermodynamics states that at absolute zero, where the amplitude of oscillation is zero, entropy is equal to zero.

Each of the bonds that hold matter together can resonate in several independent ways, known as degrees of freedom. Each degree of freedom has certain natural frequencies, normal modes, of oscillation that are dependent on the masses of the atoms and the strength of the electrodynamic forces involved. It is the "thermal motions of the molecules, their bonds, vibrations, rotations, and excitations" [*Grossman*, 2014] that store microscopic thermal energy within matter. Indeed, the capacity of a material to store heat is observed to increase with increasing number of degrees of freedom of oscillation within the material [*Grossman*, 2014; *Halliday et al.*, 2013]. This is why greenhouse gases absorb significant amounts of infrared energy. Greenhouse gases have three or more atoms, and thus have many more degrees of freedom of motion relative to each other than do molecules with only one or two atoms. Molecules of greenhouse gases can stretch symmetrically and asymmetrically, scissor, rock, wag, and twist in addition to the six degrees of freedom available to molecules with only two atoms.

Thermal energy stored in the bonds that hold matter together is referred to in thermodynamics as internal energy. A body of matter can be described as having three types of energy: 1. macroscopic potential energy (the potential to be displaced in some direction, as by the force of gravity), 2. macroscopic kinetic energy (when actually being displaced in some direction), and 3. microscopic internal thermal energy (due to internal oscillations at the molecular level with no net movement of the body in some direction). The atomic-scale dimensions of these oscillators are very small, so their natural frequencies of oscillation at room temperature (23^{o}C, 296K) are very high, around 30.6 x 10^{12} cycles per second, i.e. 30.6 trillion cycles per second, or 30.6 terahertz (THz). When matter becomes warmer, the amplitudes of these oscillations increase at all frequencies, and especially at the highest frequencies.

Thermal energy is oscillation of all the normal modes, of all the degrees of freedom, of all the bonds holding matter together. Thermal energy flows toward thermal equilibrium primarily via resonance but also through mechanical jostling of molecules as part of conduction. When the air surrounding a body of matter is cooler than the body, thermal energy on the surface flows outward as radiation, which consists of the frequencies and amplitudes of oscillation on the surface of the body. If the air surrounding the body is hotter than the body, then radiation is absorbed by the body. Heat only flows from hot to cold. A gas molecule will spontaneously absorb, via resonance, the energy from radiation only at the natural frequencies of oscillation of the bonds holding the molecule together and only when the amplitude of oscillation at a given frequency is larger in the radiation than in the molecule. Another body of matter will only absorb radiation when the amplitude of oscillation at a given frequency is higher than the amplitude of oscillation at that same frequency on the surface of the other body.

Thus thermal energy is frequencies, is transferred in matter, in air, and in space as frequencies, and is absorbed as frequencies. There is no reason to think of thermal energy in terms of particles and there is no need to think of thermal radiation in terms of waves except to explain wave-like characteristics in the immediate presence of matter under certain conditions.

6. Temperature Results From a Very Broad Spectrum of Frequencies of Oscillation

Since *Newton* [1704], physicists studied thermal radiation from black bodies by using prisms to separate the frequencies spatially and then measuring the thermal effects of narrow bands of frequencies typically on a thermopile or resistor. For infrared radiation, which does not have enough energy to penetrate glass, they made prisms out of halite. *Wien* [1897] proposed a mathematical law that described the observed distribution of thermal effects well at high frequencies, but new experiments [*Lummer and Pringsheim*, 1899] showed that Wien's distribution law did not work well at low frequencies, in the infrared. By late 1900, Planck, thinking in terms of resonators, derived a new law that described observations much more accurately at both high and low frequencies [*Gearhart*, 2008]. Planck ended up simply adding the term -1 after the exponential function in the denominator of Wien's law as a "fortunate guess" [*Gearhart*, 2008]. Planck's law (Figure 2) is

$$B_v(T) = hv\left(\frac{2v^2}{c^2}\right)\left(\frac{1}{e^{hv/k_BT} - 1}\right)$$

where $B_v(T)$ is the radiation intensity as a function of absolute temperature (T), frequency (v), and the velocity of light (c). Note that the exponential function divides the microscopic energy of oscillation (hv) by the Boltzmann constant (k_b), the energy per degree Kelvin, times the temperature (T).

Since electromagnetic radiation is induced by motion of charge on the surface of the radiating body, Planck's law also describes the frequencies and amplitudes of oscillation on the surface of the body. Temperature, thus, involves frequencies of oscillation extending over a very broad continuum. A black body is defined as a perfect absorber and emitter of radiation at all of these frequencies. The olive line shows radiation from the filament of an incandescent light bulb. The purpose of a light bulb is to provide visible light, but note how the visible spectrum is only a small part of the radiation provided. This is why an incandescent light bulb feels very hot and uses many watts of power to operate. A fluorescent light bulb or a light-emitting diode (LED), on the other hand, can produce light at only a few visible frequencies, is not hot to touch, and uses much fewer watts of power to operate. The black lines in Figure 2 are the frequencies of infrared radiation absorbed by carbon dioxide [*Rothman et al.*, 2013], less than 10% of the frequencies emitted by Earth (green line). Radiation resulting from these very limited frequencies of absorption would not feel warm

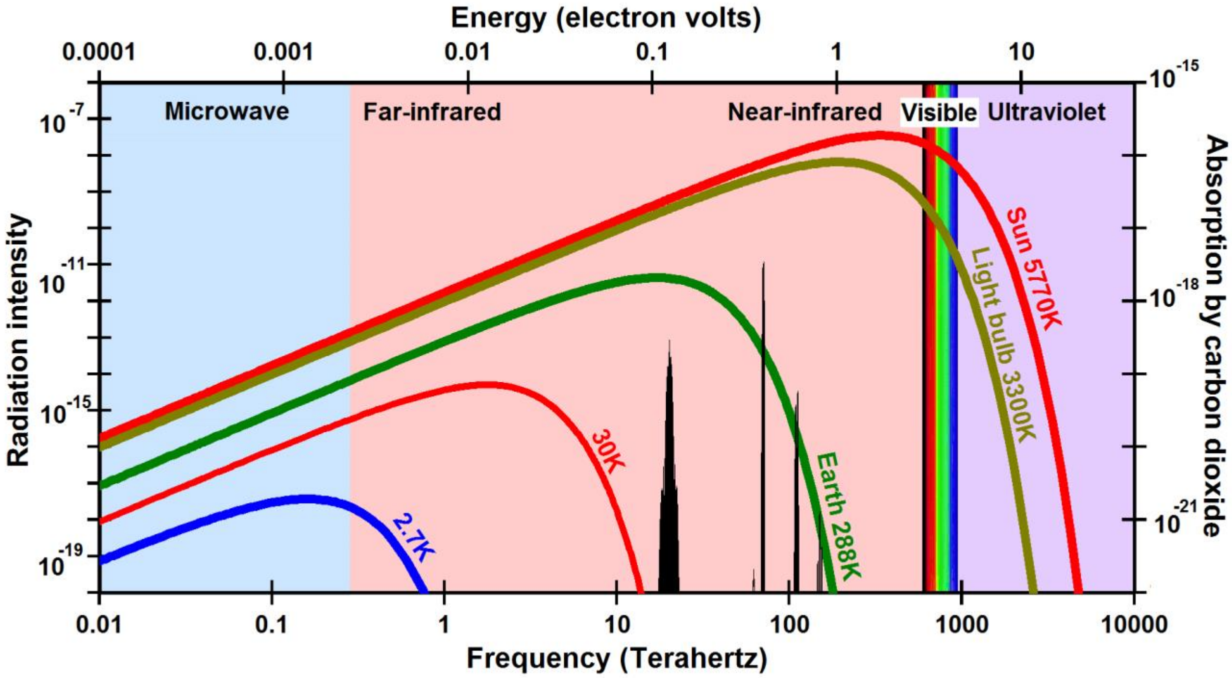

Figure 2. Planck's law calculates the intensity of radiation at each frequency of oscillation as a function of the temperature in Kelvin of a black body at thermal equilibrium.

The radiation intensity on the y-axis was measured typically as the thermal effect of the narrow band of radiation on a thermopile or resistor, the change in temperature. This became thought of as the spectral radiance in units of watts, or joules per second, per steradian per square meter per hertz. Planck thought of $E=h\nu$ as a handy mathematical trick, but did not seem to recognize that since energy is directly proportional to frequency, which is plotted on the x-axis, then energy should be plotted as an alternative x-axis shown at the top of Figure 2. Since intensity or brightness is related to the amplitude of oscillation of an atomic oscillator, Planck's law should be formulated as amplitude of oscillation on the y-axis as a function of frequency of oscillation on the x-axis, the two physical properties of electromagnetic radiation. Amplitude of oscillation would not have been easy to measure in 1900. Experimental data is now needed to measure the amplitude of oscillation as a function of frequency for black bodies at different temperatures and this should lead to a more accurate formulation of Planck's law. While this would change the units and scale of the y-axis and may change the shapes of the curves slightly, it is unlikely to change the relationships of the different curves to each other.

What is clear from Figure 2, is that to warm a body of matter, you must increase the amplitude of oscillation at every frequency and these increases must be particularly great at the higher frequencies. This is even clearer in Figure 3 showing Figure 2 plotted with a linear x-axis. A body can only be warmed by radiation from a hotter body. Radiation from Earth, no matter how efficiently it is radiated back to Earth, does not contain high enough amplitudes and frequencies of oscillation to warm Earth.

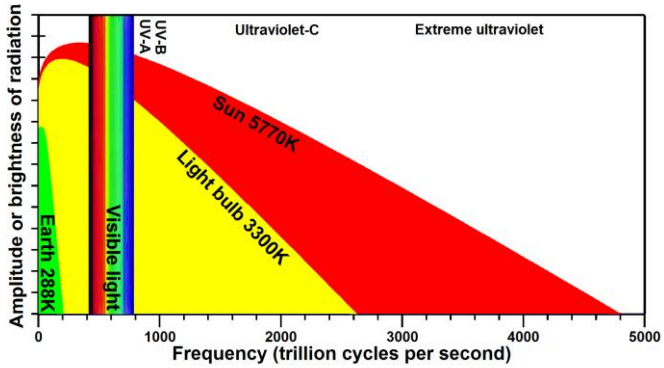

Figure 3. Planck's law plotted with a liner x-axis showing that radiation from Earth does not contain high enough amplitudes and frequencies of oscillation to warm Earth.

7. Mistaken Assumptions About Greenhouse Warming

Tyndall [1859] observed in the laboratory that water vapor, carbon dioxide, methane, and some other gases absorb infrared radiation. It is widely assumed that an increase in the concentrations of any of these gases, therefore, by conservation of energy, leads to warming of the air containing them. The only attempt to quantify this warming that I can find described in the literature was by *Ångström* [1900] who found the warming effect to be minimal.

We now understand that infrared energy is absorbed by increasing the amplitudes of oscillation of all the degrees of freedom of all the bonds holding the molecules together (vertical black lines in Figure 2). Temperature of a gas, however, is proportional to the average translational velocity squared of all the molecules making up the gas. It is commonly assumed that bond energy is converted into velocity of molecules during myriads of collisions. The efficiency of such conversion has not been quantified. Furthermore, if the law of equipartition applies, which is widely assumed, the energy is partitioned equally among all degrees of freedom, not just the three degrees of freedom of translational velocity.

Global warming is all about increasing heat content of air, land surface, and especially oceans, but very little broadband heat is actually absorbed by greenhouse gases. Carbon dioxide, for example, makes up only 0.04% of the molecules in air. Each carbon dioxide molecule only absorbs a small change in amplitude of oscillation for less than 10% of the infrared frequencies emitted by Earth (Figure 2). Greenhouse gases do not appear to absorb enough heat to be a major contributor to global warming. I am offering $10,000 to the first scientist who can prove experimentally that greenhouse gases caused more warming of Earth since 1970 than caused by ozone depletion [*Ward*, 2015].

According to the IPCC, it is assumed that "greenhouse gases, clouds, and (to a small extent) aerosols … emit infrared radiation in all directions, but, everything else being equal, the net amount emitted to space is normally less than would have been emitted in the absence of these absorbers because of the decline of temperature with altitude in the troposphere and the consequent weakening of emission" [*Planton*, 2013]. Far more heat is transferred through the troposphere by hot air rising and by convective motion of hot air from the tropics toward the poles than by radiation.

Many scientists assume that radiation from layers of gas in the atmosphere is absorbed by Earth, warming Earth. Temperatures in the troposphere decrease with increasing altitude at an average lapse rate of 6.5K per km and are therefore colder than Earth's surface. When radiation arrives at Earth's surface that is colder than Earth's surface, heat will flow by resonance out from Earth's surface, not into Earth. Heat can only flow from hot to cold, from a warmer body to a colder body (Figure 3), the second law of thermodynamics.

Climate models calculate that there is more energy in the infrared absorbed by greenhouse gases than in the ultraviolet-B reaching Earth when ozone is depleted. These models are based on the idea that the level of energy is the same at every frequency and that amounts of energy are additive so that they integrate across spectral lines of absorption to calculate total energy. As explained above, microscopic thermal energy is a function of frequency, which is not additive.

Trenberth and Fasullo [2012] and [*Wild et al.*, 2013] conclude that downwelling radiation from greenhouse gases in the atmosphere (333 and 342 W/m^2, respectively) is more than twice as much as incoming solar radiation absorbed by Earth's surface (161 W/m^2). This does not make physical sense. Do you get hotter standing in sunlight or moonlight? The basic problem here is that thermal energy is not additive so that calculating radiative forcing in watts per square meter is not correct.

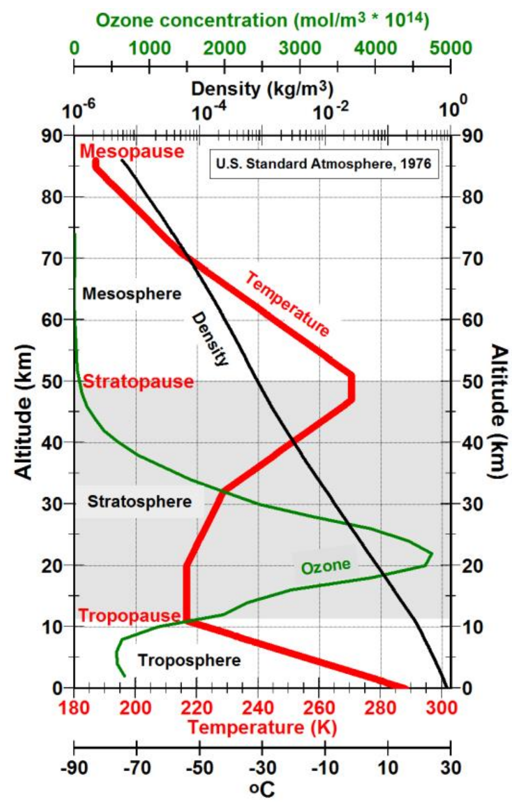

Figure 4. Temperature and density of Earth's atmosphere [*Committee on Extension to the Standard Atmosphere, 1976*] and mid-latitude ozone concentration [*Krueger and Minzner*, 1976].

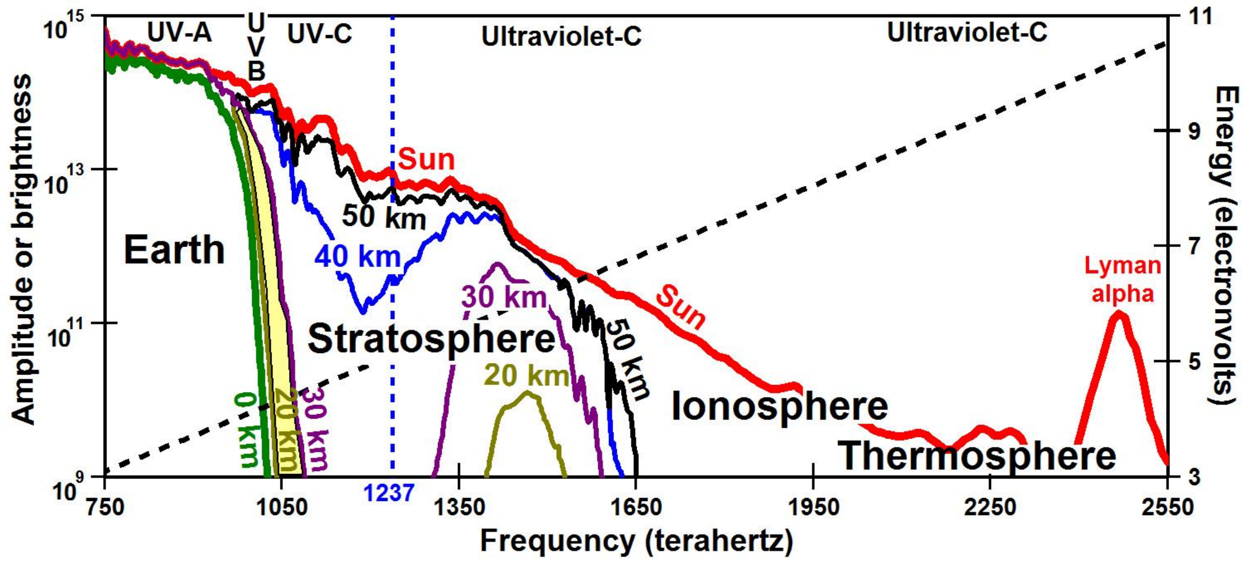

Figure 5. Amplitude or brightness of solar radiation as a function of frequency of oscillation at the top of the atmosphere (red line), and at altitudes of 50, 40, 30, 20, and 0 km.

If E=h*v*, then greenhouse warming theory does not even appear to be physically possible. There simply is not enough energy or heat absorbed by greenhouse gases to play a major role in global warming.

8. The Highest Energy Solar Radiation is Absorbed in the Upper Atmosphere
While the structure of the atmosphere varies by latitude and region over many timescales, the U.S. Standard Atmosphere (Figure 4) provides a useful basis to generalize at mid-latitudes. The troposphere is heated from below primarily by convective cooling of Earth's sun-warmed surface. On average, atmospheric temperatures drop from 288K at the surface to 217K at the tropopause (11 km), a lapse rate of 6.5K per km. Everything above the tropopause, however, is heated primarily from above by solar ultraviolet radiation. The actinic flux of solar radiation at several altitudes is shown in Figure 5 plotted in units of photons cm^{-2} s^{-1} nm^{-1} from Figure 7 of *DeMore et al.* [1997] but labeled amplitude or brightness to be consistent with the frequency model of radiation described in this paper. As in Planck's law (Figures 2 and 3), the y-axis scale will need to be changed based on new experimental data. Also shown by the red line is solar radiation at the top of the atmosphere [*Gueymard*, 2004].

It is clear in Figure 5 that most frequencies of solar radiation greater than 1650 THz are absorbed above the stratopause at 50 km (black line) and primarily above the mesopause at 85 km by the Schumann-Runge absorption continuum of oxygen (1703-2221 THz) (Figure 6) and by the Lyman-Birge-Hopfield absorption bands for nitrogen (1763-2141 THz), both causing dissociation [*Finlayson-Pitts and*

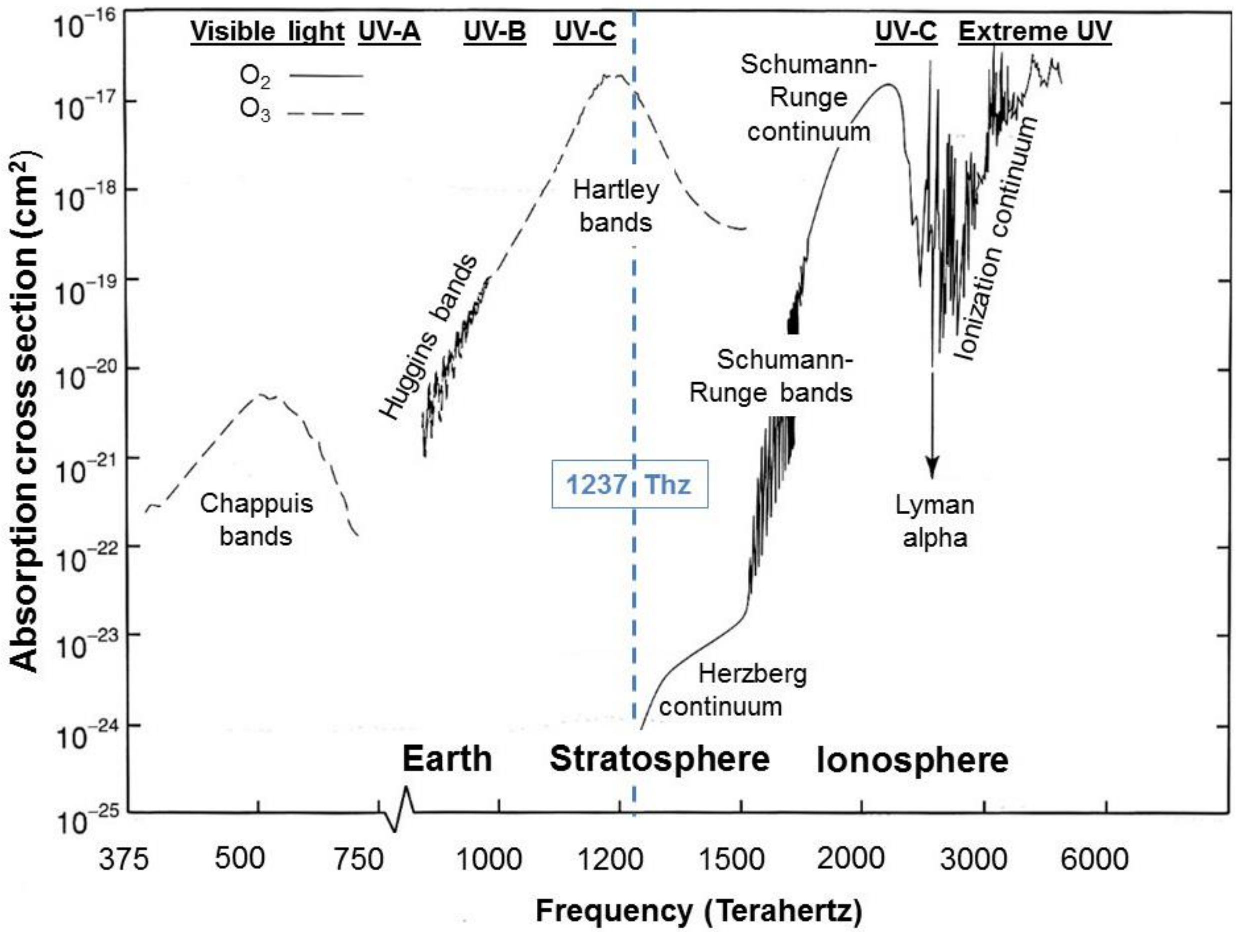

Figure 6. The amount of absorption of solar radiation by oxygen (solid lines) and by ozone (dashed lines) as a function of frequency is low in the Herzberg continuum, just to the right of the 1237 THz blue dashed line, explaining the minimal absorption by an altitude of 20 km between 1350 and 1600 THz shown in Figure 5. Replotted as a function of frequency from Figure 3.5 of *Liou* [2002].

Pitts, 1999]. When a molecule of gas is dissociated, the pieces fly apart at high velocity. Since temperature of a gas is proportional to the average velocity of all the molecules squared, dissociation turns bond energy directly into temperature. High frequency ultraviolet and extreme ultraviolet radiation also ionize many gas species, forming the ionosphere (60 to 1000 km) and the largely overlapping thermosphere (>85 km).

The stratosphere is warmed primarily by oxygen molecules absorbing solar ultraviolet-C radiation causing dissociation at frequencies in the vicinity of 1237 THz (dashed blue line, Figures 5 and 6) and ozone absorbing and being dissociated by ultraviolet-C and ultraviolet-B in the Hartley bands from 1000 to 1500 THz but peaking from 1150 to 1250 THz. The dissociation of oxygen and ozone proceed in the Chapman cycle over and over again so that the average lifetime of a molecule of ozone is only approximately 8.3 days. There is more than enough oxygen to absorb all available solar energy with frequencies in the vicinity of 1237 THz and continual dissociation of oxygen, formation of ozone, and dissociation of ozone is what primarily heats the stratosphere. Gases such as carbon dioxide and sulfur dioxide are dissociated at frequencies between 1350 and 1550 THz but are not available in large enough concentrations to absorb all of the solar energy in this range. Earth's early atmosphere, which had low concentrations of oxygen, would have had a very different structure.

The major warming observed in Earth's atmosphere is in the stratosphere (Figure 4), where temperatures at the stratopause, 50 km above Earth's surface, are maintained approximately 54K warmer than temperatures at the tropopause. Temperatures at the stratopause vary greatly with season but commonly range from 260K to 276K in the tropics, 252K to 280K in mid latitudes, and 253K to 293K near the poles [*France et al.*, 2012]. The stratosphere acts as an "electric" blanket around Earth, in the sense that the energy to warm the blanket does not come from the body under the blanket, i.e. from Earth, but primarily from a distant source, in this case Sun.

It is commonly argued [*Elert*, 2016] that the warming effect of greenhouse gases is proven by the fact that surface temperatures on Earth without an atmosphere should be 255K, which is 33ºC colder than what we enjoy today. Yet 255K is very close to the average temperature of the stratopause [*France et al.*, 2012]. Clearly Earth is kept warm by the stratospheric blanket heated by solar ultraviolet radiation. The stratopause is the key radiant surface into space of the Earth/atmosphere system and it can continue to radiate only because heat from both a Sun-warmed stratosphere and a Sun-warmed Earth rises continuously through the stratosphere, replacing the heat radiated from the stratopause. Temperature drops with increasing altitude above the stratopause up to the mesopause (85 km), the coldest (173K) altitude in Earth's atmosphere. Decreasing temperatures in the mesosphere would foster convection, just as in the troposphere, although the air density has become so small (Figure 4) that the amount of heat transported would be small.

Clearly from Figures 5 and 6, the highest levels of energy of sunlight are the first to interact with the upper atmosphere, forming the thermosphere and ionosphere. The maximum frequency (energy level) of solar radiation reaching a given altitude generally decreases with altitude controlled primarily by the absorption curves of nitrogen and oxygen that make up 78% and 21% of the atmosphere, respectively. General climate models, based on equations by *Maxwell* [1873] and *Arrhenius* [1896], however, currently assume that the level of thermal energy is the same for

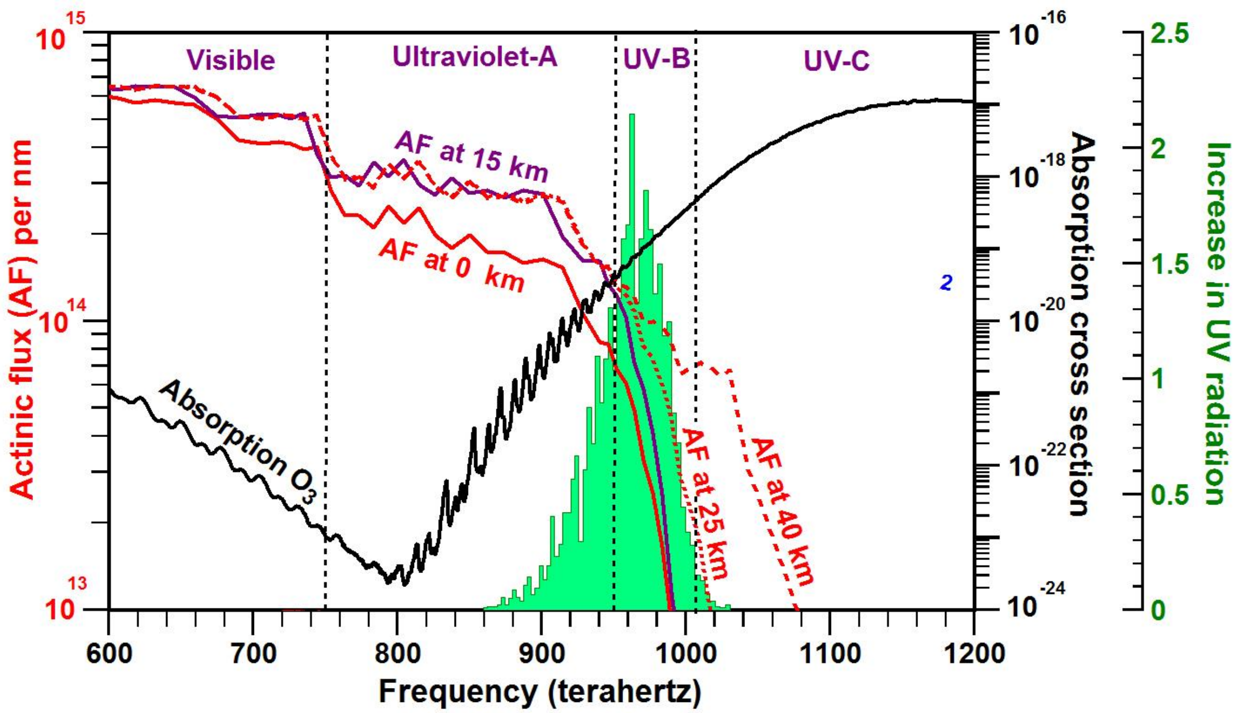

Figure 7. Percent increase in ultraviolet radiation (green) reaching the lower troposphere when the ozone layer is depleted by 1%. These frequencies between 900 and 1000 THz are the most energetic solar radiation to reach Earth.

every frequency, integrating the amount of energy as a function of frequency, adding microscopic energies that are not additive.

9. When the Ozone Layer is Depleted, More Ultraviolet-B Radiation Reaches Earth

By an altitude of 20 km, nearly all ultraviolet-C (1071-2998 THz) and ultraviolet-B (952-1071 THz) radiation has been absorbed (Figure 5), forming the details of the atmosphere above. Under atmospheric conditions normal before ozone depletion began around 1970, most ultraviolet-B radiation was absorbed by the ozone layer (yellow shaded area) extending primarily from altitudes of 30 km down to 15 km (Figure 4). When the ozone layer is depleted, there is less ozone to absorb ultraviolet-B radiation. This causes the ozone layer to cool, and more ultraviolet-B radiation is observed to reach Earth [*Herman*, 2010], warming Earth. The increase in radiation reaching Earth when the ozone layer is depleted by 1% is shown in Figure 7 as calculated by *Madronich* [1993] and discussed by *Madronich et al.* [1995] [1998]. Note that the frequencies are primarily between 900 and 1000 THz, with a peak near 967 THz. These are the highest frequency, the most-energetic, the "hottest" radiation reaching Earth. The higher the energy of the radiation, the higher the temperature to which the absorbing body can be raised.

A black body whose Planck curve (Figures 2 and 3) has peak amplitude at 967 THz would, according to Wien's displacement law, have a temperature close to 9350K, but because amplitude of oscillation at this frequency from Sun is less, because amplitude of oscillation decreases inversely with the square of the distance from Sun to Earth, and because the angle of incidence and duration of exposure vary, ultraviolet-B radiation will not warm Earth anywhere near that much. However, because frequency of oscillation (level of energy) does not change with distance, ultraviolet-B radiation does have the level of energy to burn skin, cause sunburn and skin cancer, sublimate snow, melting glaciers, and evaporate moisture. Even more important, ultraviolet-B radiation has the energy to penetrate tens of meters into the ocean [*Tedetti and Sempéré*, 2006], so that thermal energy absorbed during daytime cannot be radiated back into the atmosphere at night as is common on land. Thus ocean heat content [*Levitus et al.*, 2012] will continue to increase, as observed, until ozone levels return to levels typical before 1970, commonly thought to be many decades in the future [*Solomon*, 1999].

The first routine measurements of total column ozone, looking up from Earth, began in Arosa Switzerland in 1927 [*Staehelin et al.*, 1998]. Ozone concentrations vary substantially by the second, the hour, the day, and the month. Furthermore, measurements can only be made several times per day under certain conditions. On some days no measurements can be made. Annual average ozone observations, however, show some distinct changes in trend (Figure 8). The dashed gray line with blue data markers shows, for 1964 to 2009, the annual mean area-weighted total ozone deviation at all stations in northern mid-latitudes (30^{o}N to 60^{o}N) compared to 1964 to 1980 means scaled from -8% at the bottom of the figure to 10% at the top [*Douglass et al.*, 2011]. Years of increasing or decreasing ozone are nearly identical for Arosa and for this area-weighted mean with small differences in amplitude. Thus, the Arosa data provide a reasonable approximation for annual mean total column ozone throughout northern mid-latitudes since 1927.

Ozone at Arosa averaged 331 Dobson units (DU) until 1974, fell 9.4% to 300 DU by 1993 and began generally rising again until 2011. The long-term decrease in ozone has been attributed in detail [*Molina and Rowland*, 1974] to the chlorine-catalyzed destruction of ozone due to an increase in the concentration of anthropogenic tropospheric chlorine (green line, y axis inverted) [*Solomon*, 1999] caused by manufacturing CFCs used widely as refrigerants, spray-can propellants, solvents, and such. When the Antarctic ozone hole was discovered [*Farman et al.*, 1985], scientists and politicians moved rapidly to pass the Montreal Protocol on Substances that Deplete the Ozone Layer, which was ratified beginning in 1987

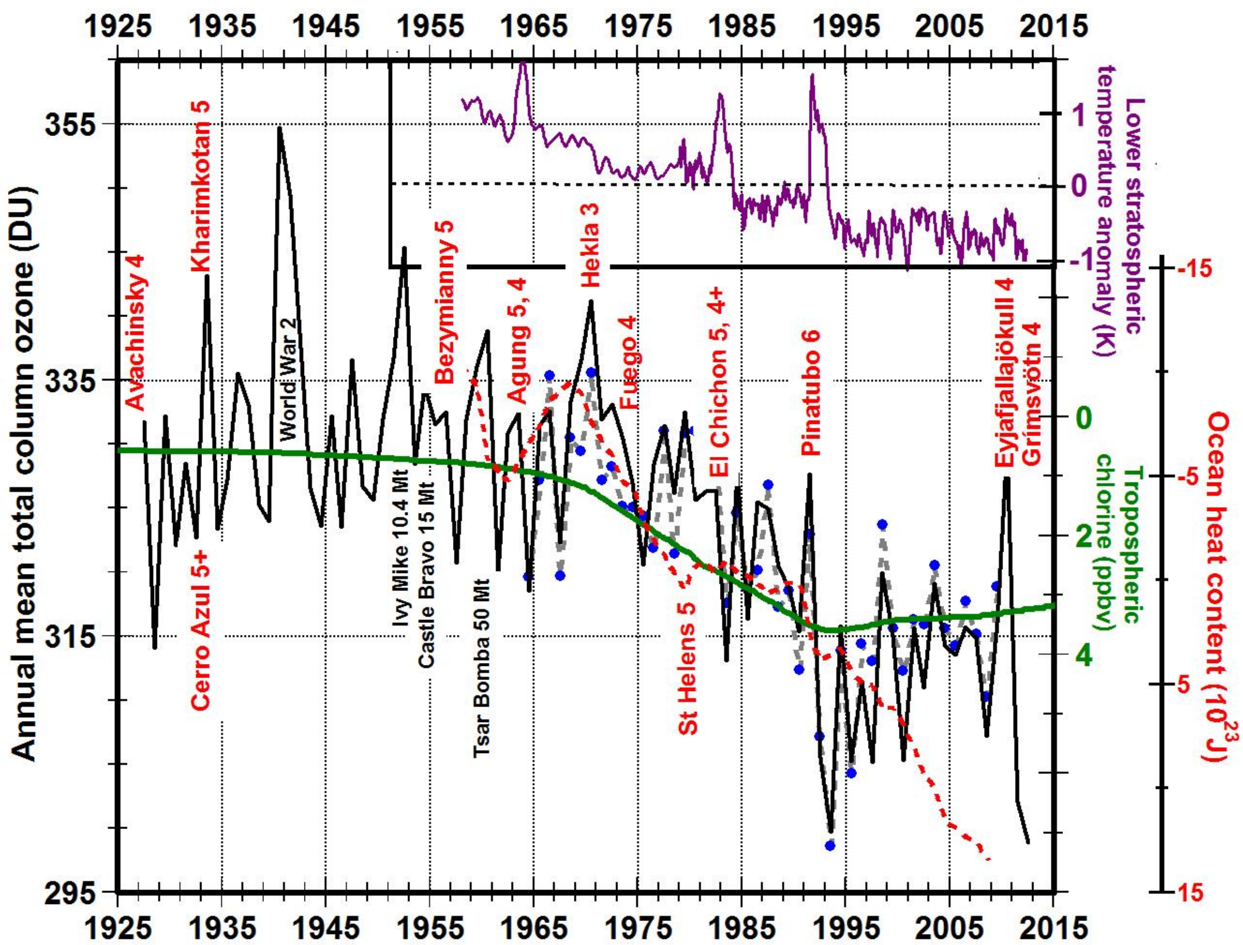

Figure 8. Mean annual total column ozone above Arosa, Switzerland (black line), anthropogenic tropospheric chlorine (green line), ocean heat content (dashed red line) and lower stratospheric temperature anomaly (purple line). Note that the y axes of the green and dashed red lines are inverted. The dashed gray line with blue data markers shows, for 1964 to 2009, the annual mean area-weighted total ozone deviation from the 1964 to 1980 means for northern mid-latitudes.

and took effect January 1, 1989. The Montreal Protocol mandated cutback in manufacturing of CFCs and led to a decrease in tropospheric chlorine beginning in 1993. Long-term chlorine concentrations are expected to return by 2040 to levels that were prevalent before the late-1970s [*Solomon*, 1999].

The purple line in Figure 8 shows cooling of the lower stratosphere, the ozone layer, since the first measurements in 1956. This cooling occurred mostly “as two downward ‘steps’ coincident with the cessation of transient warming after the major volcanic eruptions of El Chichón and Mount Pinatubo” [*Thompson and Solomon*, 2009] and a similar downward step following the 1963 eruptions of Agung volcano [*Randel*, 2010]. The transient warming is likely caused by dissociation at frequencies between 1350 and 1550 THz (Figure 5) of carbon dioxide and sulfur dioxide erupted into the stratosphere. The long-term decrease in temperature of this very dynamic system is almost certainly caused by the observed ozone depletion.

10. Volcanic Eruptions Also Deplete the Ozone Layer

The greatest depletion of ozone since 1927 was in 1992 and 1993, following the June 1991 eruption of Mt. Pinatubo in the Philippines, the largest volcanic eruption since 1912. The second largest depletion of ozone was of a similar amount in 2011 and 2012, following the much smaller eruption of Eyjafjallajökull in Iceland during March-April 2010. Pinatubo erupted 3 to 16 Mt of chlorine [*Gerlach et al.*, 1996] plus bromine and fluorine as high as 35 km [*Self et al.*, 1996]. *Tabazadeh and Turco* [1993] argue that chlorine is water soluble in the form of HCl and would, therefore, primarily be rained out of the eruption cloud, leaving only the ~1% increase in stratospheric chlorine observed [*Mankin et al.*, 1992; *Wallace and Livingston*, 1992]. Tabazadeh and Turco conclude that chlorine in the stratosphere is caused more by manufactured CFCs than by volcanoes. The data in Figure 8 suggest, however, that depletion at mid-latitudes caused by the eruption of Mt. Pinatubo within two years was slightly more than the depletion caused by CFCs that cumulated over 25 years. This volcano-caused depletion appears to recover in less than ten years, while CFCs are expected to remain in the atmosphere for many more decades. Given that one atom of chlorine can destroy 100,000 molecules of ozone [*Molina and Rowland*, 1974], not much chlorine is needed to explain observations. Plus bromine could play a major role in ozone depletion [*Bureau et al.*, 2000; *Salawitch et al.*, 2005].

The years with the other largest eruptions since 1927 plus a few smaller basaltic effusive eruptions in Iceland are labeled in red. It is clear from the data plotted in Figure 8 that volcanic eruptions deplete the ozone layer especially during the two years following the eruption and that we still have much to learn about the detailed atmospheric chemistry involved.

Note also in Figure 8 that the year of eruption typically shows an increase in ozone, while the next two years show a much greater decrease. *Ward* [2014] documents a 70% increase in total column ozone on February 19, 2010, northeast of Eyjafjallajökull precisely at the time when earthquakes and deformation data suggest magma started moving toward the surface from a dike at a depth of 4.5 to 6.5 km [*Sigmundsson et al.*, 2010]. The origin of this ozone is not understood. Note, however, that there is a local peak in ozone during the year of most volcanic eruptions shown in Figure 8. There are also ozone peaks in the years of major nuclear tests labeled in black and a very large and enigmatic peak during World War 2.

From December 1991 through February 1992, when ozone depletion would normally be increasing during Arctic winter, warming of up to 3^{o}C more than usual was observed in the troposphere over Canada, northern Europe, and Siberia [*Robock*, 2002]. Throughout the northern hemisphere, however, surface temperatures averaged 0.4 to 0.6^{o}C cooler than normal through 1993 [*Self et al.*, 1996]. Pinatubo ejected 491 to 921 Mt water vapor and 17 Mt sulfur dioxide [*Self et al.*, 1996] into the stratosphere where it circled Earth and spread from 30^{o}N to 10^{o}S within 21 days [*McCormick*, 1992], spreading worldwide within months. Much of the sulfur dioxide may have been dissociated by frequencies of solar radiation in the vicinity of 1500 THz [*Hydutsky et al.*, 2008] (Figure 5) leading to warming of the stratosphere (purple line, Figure 8). The water vapor and sulfur dioxide also formed a sulfuric acid aerosol whose particle sizes grew large enough (up to 0.5 µm [*Asano et al.*, 1993]) to reflect and scatter solar ultraviolet radiation and visible light attaining a mid-visible optical depth of 0.3 within months.

Cooling of global surface temperatures by approximately 0.5^{o}C for two or more years has been observed after nearly all major explosive volcanic eruptions in recorded history [*Robock*, 2000]. These volcanoes, like Pinatubo, apparently deplete the ozone layer causing winter warming within 6 to 8 months, inject megatons of sulfur dioxide into the stratosphere where is absorbs ultraviolet-C solar radiation warming the stratosphere, but primarily form aerosols in the lower stratosphere that reflect, scatter, and absorb solar radiation causing net global cooling after that time.

On August 29, 2014, Bárðarbunga volcano in central Iceland, began forming the Holuhraun lava field, erupting 1.4 km^3 of basaltic lava over an area of 85 km^2 by February 28, 2015 [*Sigmundsson et al.*, 2015], the highest rate of basalt extrusion in the world since the eruption of Laki volcano in 1783 [*Thordarson and Self*, 2003], a truly significant eruption. This type of effusive volcanic eruption, common in Iceland, Ethiopia, and Hawaii, extrudes primitive basaltic lava for days, months, centuries, and even hundreds-of-thousands of years, emits 10 to 100 times more volatiles per cubic kilometer of magma [*Freda et al.*, 2005; *Palais and Sigurdsson*, 1989; *Self et al.*, 2008], does not eject most of these emissions high enough to reach the stratosphere, does not form extensive stratospheric aerosols, and is observed to cause net warming.

The effects of manufactured CFCs and volcanic eruptions on global climate are summarized in figure 9. (a) Under conditions normal before 1965, absorption of ultraviolet-C primarily by oxygen warmed the upper atmosphere, absorption of

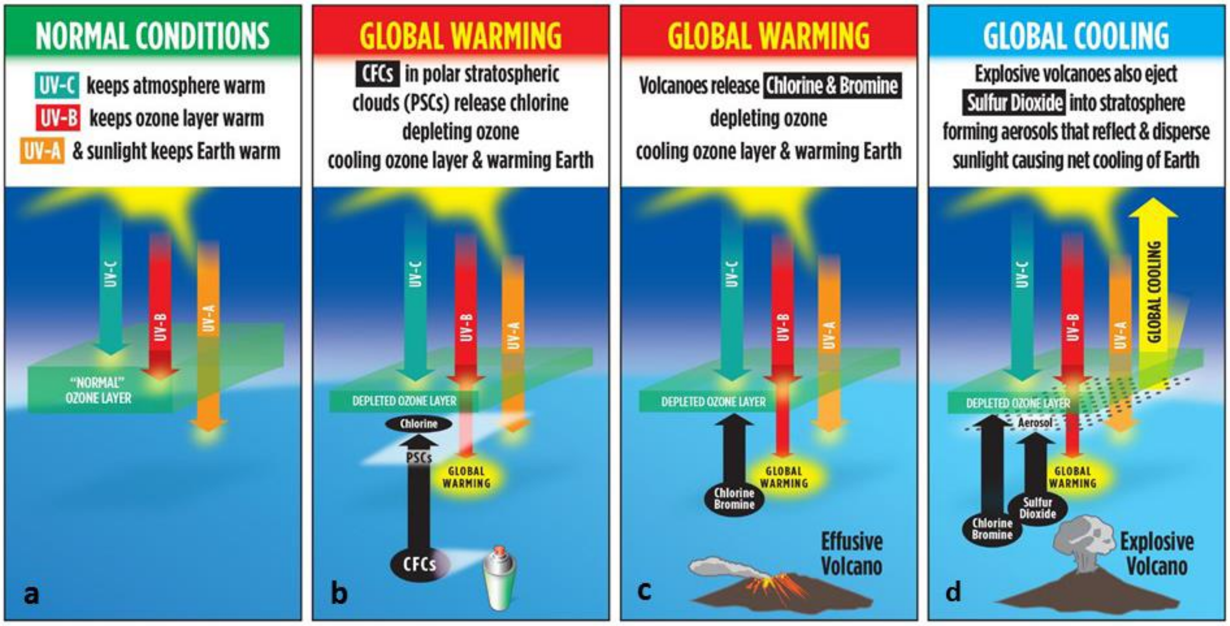

Figure 9. a) Conditions normal before 1965. b) CFCs release atoms of chlorine that deplete the ozone layer allowing more UV-B to reach Earth. c) Effusive volcanoes emit chlorine and bromine, which deplete ozone, leading to global warming. d) Explosive volcanoes similarly deplete ozone, but form globe-encircling aerosols that reflect, scatter, and absorb solar radiation, causing net global cooling.

ultraviolet-B primarily by ozone warmed the ozone layer, and ultraviolet-A and visible light warmed Earth. (b) Manufactured CFCs, when they rise high in the stratosphere, are broken down by ultraviolet-C into molecules that release chlorine atoms especially in the vicinity of very cold polar stratospheric clouds (PSCs). One atom of chlorine can destroy 100,000 molecules of ozone, allowing more ultraviolet-B than usual to reach Earth's surface, thus cooling the ozone layer and warming Earth. (c) Effusive volcanoes emit chlorine and bromine, which deplete ozone, leading to global warming. (d) Explosive volcanoes similarly deplete ozone, but also eject megatons of water vapor and sulfur dioxide into the lower stratosphere, forming globe-encircling aerosols whose particle sizes grow large enough to reflect, scatter, and absorb sunlight, causing net global cooling.

When explosive volcanoes causing net global cooling occur several times per century, they can increment the world into an ice age [*Ward*, 2016]. When effusive basaltic volcanoes that cause net global warming were relatively continuous in Iceland from 11,750 to 9,375 years ago, they warmed the ocean enough to warm the world out of the last ice age [*Ward*, 2016]. The balance between these two types of volcanism is observed throughout Earth history and is determined by the detailed motions of tectonic plates—explosive volcanoes are more common where plates are converging, effusive volcanoes are more common where plates are spreading apart.

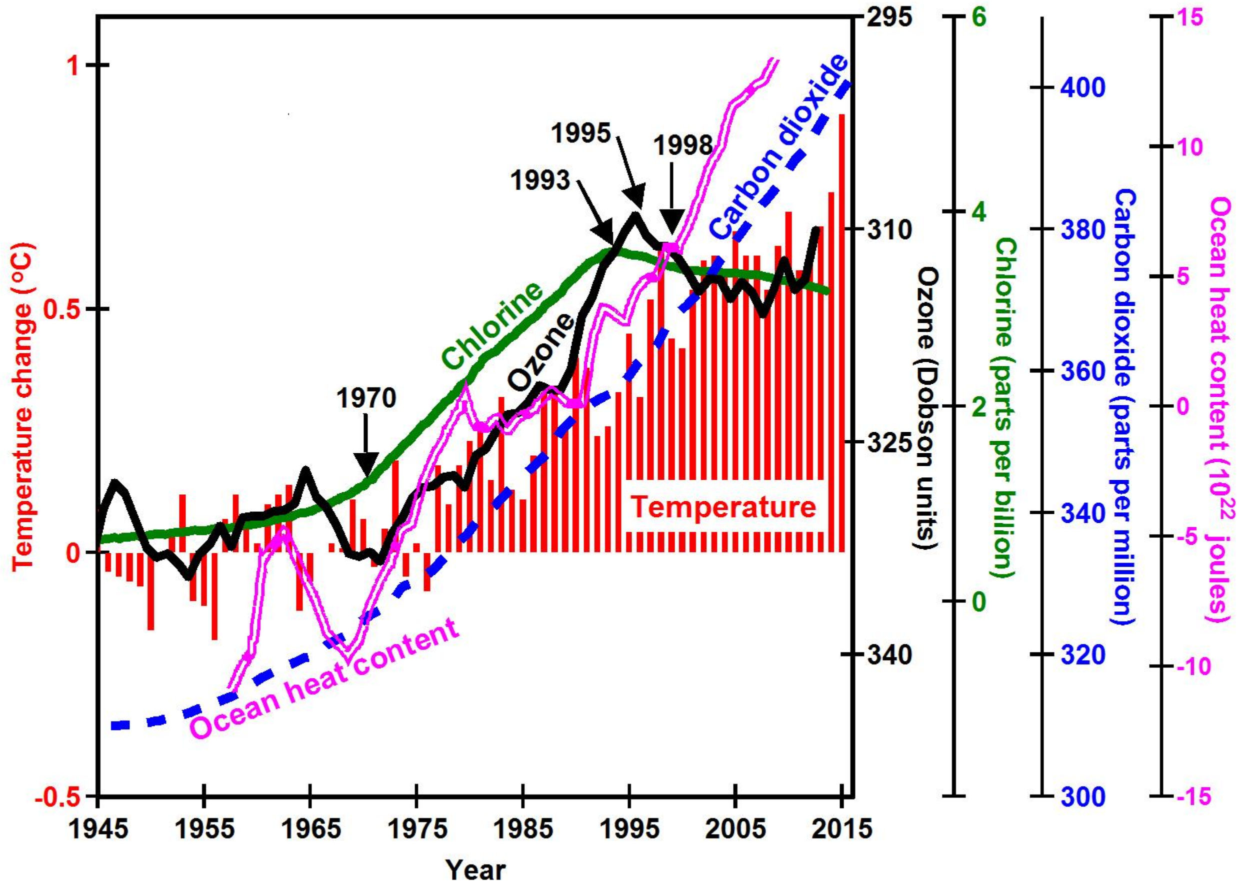

Figure 10. The increase in tropospheric chlorine (green line), caused by manufacturing of chlorofluorocarbon gases, led to increased ozone depletion (black line), which led to increased temperature (red bars).

11. Ozone Depletion Appears to Have Warmed the World Since 1945

The red vertical bars in Figure 10 show global surface temperature anomalies relative to a base period from 1971 through 2000 [*NOAA*, 2016b]. The three other major compilations of global temperature data show very similar results (Figure 3.2 in *Ward* [2016]) [*Berkeley Earth*, 2015; *GISS*, 2016; *HadCRUT4*, 2016]. Note that temperatures did not change much from 1945 to 1970, rose sharply from 1970 to 1998, did not change much from 1998 through 2013, a period known as the global warming hiatus [*Fyfe et al.*, 2016], and rose sharply again beginning in 2014. Meanwhile concentrations of carbon dioxide at Mauna Loa [*NOAA*, 2016a] (dashed blue line), rose at ever increasing rates, showing no relationship to the sudden changes in temperature trend around 1970, 1998, and 2014.

In the 1960s, CFCs became popular for use as refrigerants, spray-can propellants, solvents, and foam blowing agents because they do not interact with most other chemicals. By 1970, a wide variety of products in spray cans had become available with CFCs as propellants. Emissions of these human-manufactured, chlorine-bearing gases began increasing by 1965 (green line, Figure 10) [*Solomon*, 1999].

By 1970, total column ozone, measured poleward of the tropics, became depleted by as much as 50%, especially in the southern hemisphere, resulting in the well-known Antarctic ozone hole that reaches its peak development during mid to late local winter (black line) [*NASA*, 2016].

Molina and Rowland [1974] discovered that CFCs can be broken down by ultraviolet radiation high in the stratosphere, leading to ozone depletion. When the Antarctic ozone hole was discovered by *Farman et al.* [1985], scientists and politicians worked efficiently together under the Vienna Convention for the Protection of the Ozone Layer to develop the Montreal Protocol on Substances that Deplete the Ozone Layer, which became effective on January 1, 1989, limiting manufacture of CFCs. By 1993, increases in CFC emissions stopped; by 1995, increases in ozone depletion stopped, and by 1998, increases in global temperatures stopped (Figure 8). Increasing emissions of CFCs appear to have caused the rapid increase in temperature beginning around 1970. Decreasing emissions of CFCs beginning in 1993 appear to have stopped increases in ozone depletion by 1995 and further increases in temperature by 1998. Because CFC concentrations continue to decrease slowly, further increases in temperature due to CFCs are not anticipated. Man caused the warming beginning in 1970 and man corrected this problem by passing the Montreal Protocol.

Annual average ozone concentrations have remained depleted since 1998 by approximately 4% in northern mid-latitudes compared to pre-1970 concentrations. The resulting increased influx of ultraviolet-B radiation continues to increase ocean heat content (fuchsia double line) [*Levitus et al.*, 2012] because it penetrates tens of meters into the ocean [*Tedetti and Sempéré*, 2006], from which depth the energy is not radiated back into the atmosphere at night.

Ozone depletion ranges from zero in the tropics to more than 50% during late winter-early spring in polar regions. Similarly, global warming also ranges from zero in the tropics to many degrees in polar regions, suggesting a cause-and-effect relationship. The greatest global warming ever recorded by thermometers, 6.7°C, was measured from 1951 to 2003 on the Antarctic Peninsula [*Hughes et al.*, 2007], and this was the greatest warming observed for this region in 1300 years [*Mulvaney et al.*, 2012]. There was also significant warming in West Antarctica [*Bromwich et al.*, 2013] and in the Arctic [*Trenberth et al.*, 2007]. Amplification of warming temperatures in the polar regions, which has been widely observed, is fully consistent with ozone depletion theory because the greater the ozone depletion, the greater the warming. It is very difficult to explain Arctic amplification with greenhouse warming theory [*Serreze and Barry*, 2011].

Figure 11 shows the last frame of an animation of global surface temperature anomalies [*HadCRUT4*, 2016] clockwise by month since 1850 in the center of the figure [*Hawkins*, 2016]. Note that the most rapid warming since 1850 had begun clearly by May 2015 (white arrow), following the eruption of Bárðarbunga from August 2014 through February 2015. The hottest year on record was 2015 and 2016 is shaping up to be significantly hotter (Figure 11). The Bárðarbunga eruption, the highest rate of extrusion of primitive basalts since 1783, appears to have caused this warming by depleting the ozone layer. Since depletion is typically greatest during years 2 and 3 after an eruption (Figure 8), continued warming in 2017 is unlikely unless Bárðarbunga were to erupt again. A magnitude 4.2 earthquake under Bárðarbunga on April 8, 2016 [*Iceland-Monitor*, 2016], shows another eruption is possible.

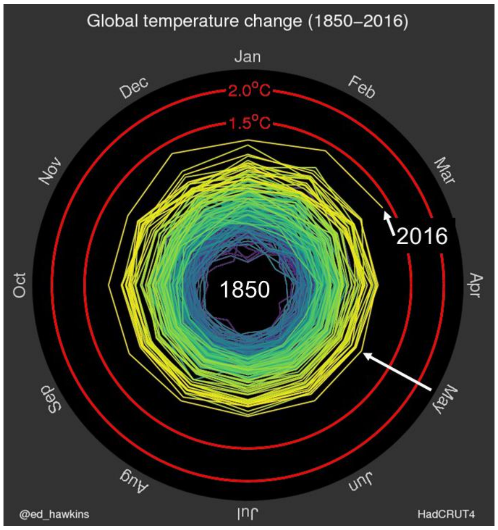

Figure 11. The most rapid increases in global temperature anomaly since 1850 in the center, were since March, 2015, following the Bárðarbunga eruption from August 2014 through February 2015.

Ozone depletion related to CFCs is likely to continue for several decades [*Solomon*, 1999] so that ocean heat content will continue to rise. The oceans are the true thermostat of the climate system. They hold nearly all of the heat content. We have moved Earth's thermostat up, and the only natural way to cool the oceans is with more frequent eruptions from explosive volcanoes. Although we have warmed the world on average close to 1°C since 1965, and although the world will remain warmer than it was before, we can take comfort in the realization that the major warming predicted by climate models based on greenhouse warming theory has not occurred since 1998 and is unlikely to occur in the future.

12. We Need to Understand the Chemistry of Ozone Depletion Much Better

The most interesting observation in Figure10 is that surface air temperature anomalies only rose from 1970 to 1998, as long as the amount of ozone depletion was increasing. When ozone depletion was no longer increasing, a new equilibrium was established between the amount of ultraviolet-B reaching the lowest atmosphere and the amount of ozone pollution available to be dissociated. Soon after ultraviolet-B radiation stopped increasing in 1995, surface temperatures reached this new equilibrium, remaining nearly constant from 1998 through 2013 during the global warming hiatus.

Surface air temperatures, therefore, appear to be a function of both the amount of ultraviolet-B radiation reaching Earth and the amount of ozone pollution available to be dissociated. Global warming from 1970 to 1998 was twice as great in the northern hemisphere [*HadCRUT4*, 2016] containing 88% of world population together with most global pollution. Similarly global warming in late 1991 and early 1992 following the 1991 Pinatubo eruption was greatest in industrial areas of central North America and Europe [*Robock*, 2002]. This implies that the principal warming of air is not caused by increased ultraviolet-B radiation warming the ground and thereby keeping surface air temperatures warmer at night. Such warming of the ground would require continual flow of much more heat. Polluted areas heated in this way from above would confuse studies of the heat island effect [*EPA*, 2016a].

Under the Clean Air Act, the US Environmental Protection Agency has monitored ground-level ozone air quality at 218 stations since 1980 [*EPA*, 2016b]. Ozone air quality has improved by 33% from 1980 through 2015 and the spread of data throughout the country has decreased from ±31% to ±13%. While regulatory efforts may have led to much of this improvement, increased ultraviolet-B radiation reaching Earth because of increased ozone depletion in the stratosphere, would lead to a higher rate of ozone destruction near ground. As ozone depletion recovers, ozone air quality could get worse.

The amount of ozone depletion associated with volcanic eruptions, shown in Figure 8, varies substantially. The greatest depletion since 1927 followed the 1991 eruption of Mt. Pinatubo, the largest explosive eruption since 1912, but a similar amount of depletion followed the hundred-time smaller explosive eruption of Eyjafjallajökull in 2010 that also included an effusive eruption of 1.3 km^2 of basaltic lava. Plus the depletion of the non-explosive but dominantly effusive eruption of Bárðarbunga in 2014-2015, when the data are available, is likely to be even greater, explaining the record-setting temperatures in 2016. The amount of depletion most likely depends on magma type, amount of chlorine and bromine reaching the stratosphere by explosion versus hot air rising, the latitude of the volcano, and possibly the ambient level of ozone depletion at the time of the eruption. We need much more data quantifying the details of the link between volcanic eruptions and ozone depletion.

We also have much to learn about the detailed chemistry of ozone depletion as a function of latitude and time of year. The mechanism for ozone depletion proposed by *Molina and Rowland* [1974] caused by CFCs appears to be very important for forming the Antarctic ozone hole in late winter and early spring, but may not explain ozone depletion at mid-latitudes and throughout the year. If the average lifetime of a molecule of ozone is only 8.3 days, then depletion must occur regionally, not only in polar regions. The Brewer-Dobson circulation is not thought to move all that quickly [*Cordero et al.*, 2003]. The amount of depletion does appear to be proportional to the cumulative amount of halogens in the atmosphere from all possible sources.

13. Changes in Concentrations of Ozone Affect Weather

Ozone concentrations vary substantially by region, especially north of 45°N, as shown by daily maps [*Environment Canada*, 2016] and their animations [*Ward*, 2013a; b]. The presence of ozone indicates the presence of atmospheric warming caused by dissociation of oxygen and ozone, complicated by motion of each molecule during its lifetime. According to *Reed* [1950], "*Dobson et al.* [1929] have shown that maximum positive deviations of daily values [of temperatures] from the monthly means are generally found to the rear of surface low-pressure areas, while maximum negative deviations are found to the rear of surface highs. More recently, on the basis of more extensive measurements, *Dobson et al.* [1946] refined the earlier results and found that for many occlusions, the maximum positive deviations occur directly over the surface low rather than to the rear."

Dobson found that the total amount of ozone in the lower stratosphere correlated positively with temperature and potential temperature and negatively with density and the height of the tropopause. With the advent of satellite systems, it is now possible to observe these variations with increasing precision. What is becoming clear is that variations in ozone concentrations may be caused, in part, by dynamic changes in the atmosphere, but these changes, in turn, are partially caused by changes in the concentrations of ozone. There is much detail to work out, but it is clear that ozone plays a major role in weather and in the long-term weather patterns that we call climate.

Increased ozone depletion causes the polar vortex to become stronger, colder, and more persistent [*Waugh and Polvani*, 2010]. Changes in ozone concentrations cause changes in the shape and extent of the polar jet streams that can cause changes in the latitudes where precipitation occurs and changes in regions where excessive Arctic cold dips south into the eastern United States, Northern Europe, and Russia.

There are many ways that ozone concentrations appear to be linked to weather as well as to climate. Concentrations of greenhouse gases, on the other hand, do not vary regionally and thus do not correlate with weather.

14. Towards a More Complete Understanding of Physics

The primary reason for why greenhouse-warming theory does not appear to be physically possible is based on a fundamental problem in physics—how we think of and calculate radiant thermal energy. Based on *Maxwell* [1873] and *Einstein* [1905], we have been thinking of electromagnetic radiation as a thing, a wave or a particle, and if we have more of this thing, we have more energy. This is the macroscopic view of energy that we are all familiar with and use regularly, for example, to describe kinetic and potential energies of pieces of matter. The amount of macroscopic energy is an extensive physical property that is a function of the extent or amount of the thing and can, therefore, be added or subtracted. When you double the mass, you typically double the macroscopic energy, which is a function of mass.

Thermal energy is something fundamentally different. Thermal energy is cyclic oscillations of all the microscopic bonds holding matter together where the level of energy (E) of each microscopic oscillator is equal to the Planck scaling constant (h) times the frequency of oscillation (ν) so that $E=h\nu$. More energy means a higher <u>level</u> of energy, not a higher <u>amount</u> of energy. A higher level of energy means a higher frequency of oscillation. Energy is the actual oscillation where frequency is the level of energy and Planck's constant is the number of joules thought to be "contained in" one cycle per second. Chemical reactions occur when this level of energy is high enough; something well understood by atmospheric chemists.

Each microscopic oscillator has two physical properties: frequency of oscillation, which is color of light, and amplitude of oscillation, which is the intensity or brightness of light. Amplitude of oscillation is related to the temperature of the radiating body via Planck's law for a black body at thermal equilibrium (Figure 2). The higher the amplitude of oscillation at a given frequency, the hotter the body radiating that frequency. Frequency travels through air and space without change, even over galactic distances, meaning the level of energy of ultraviolet radiation leaving Sun is the same as the level of energy of the same radiation when it arrives on Earth. Amplitude, however, decreases inversely with the square of the distance traveled through air and space and with absorption by intervening gases. Heat is essentially about how the amplitudes of oscillation of an ensemble of oscillators flow as a function of time from oscillator to oscillator either through matter or via radiation between matter. The greatest heat flows between oscillators with the greatest difference in amplitudes because the amplitudes become equalized. Temperature for matter is defined when a very broad spectrum of all oscillations throughout a piece of matter have reached thermal equilibrium, where there is no change in the flow of heat (Figures 2 and 3).

Thermal energy is an intensive physical property that pervades matter at the atomic level and, therefore, is not a function of the extent of the matter. Intensive physical properties are not additive. It makes no physical sense to add frequencies of light together; they all coexist in air and space without interacting. Since energy is directly proportional to frequency, it makes no physical sense to add energies together. It makes no physical sense to integrate energy as a function of bandwidth, as is done by current climate models. There is no such thing as radiative forcings that can be added together, something central to current climate theory. Even the concept of watts, energy per second, needs to be redefined for thermal energy because it is a function of frequency. The higher the frequency of a microscopic oscillator, the higher the energy. The higher the energy, the higher the temperature to which the absorbing body can be raised. New experimental data are needed measuring amplitude of oscillation (intensity) as a function of frequency (energy) of oscillation in radiation from black bodies at different temperatures, recasting Planck’s law (Figures 2 and 3) in terms of these two observed physical properties of electromagnetic radiation. Then we can write new equations governing all these issues. Then all climate models will need to be rewritten.

So how do we determine the thermal effect of Sun on Earth? The thermal effect is a function of 1) frequency, 2) what frequencies are absorbed by and therefore form the atmosphere, 3) what frequencies penetrate to Earth’s surface, and 4) how efficiently this broad spectrum of frequencies is absorbed by the oceans. It is the highest frequencies that heat Earth most (Figure 3). Daily temperatures are affected most by the amplitudes of oscillation of ultraviolet-B, ultraviolet-A, and visible light reaching Earth. Ultraviolet-B is the radiation whose amplitude of oscillation varies the most by the second, by region, by latitude, by season, and by year as total column ozone in the atmosphere changes. Clouds have an effect, but ultraviolet penetrates clouds much more effectively than visible light does.

Average surface temperatures on Earth are controlled primarily by the amplitude of ultraviolet-B radiation reaching Earth. Changes in average surface temperature on Earth are, therefore, controlled primarily by changes in the amplitude of ultraviolet-B radiation. Oceans contain nearly all of the Earth/atmosphere heat content, integrating solar radiation as a function of time. Long-term climate, whether we are in an ice age, a hothouse, or somewhere in between depends on the cumulative number of major explosive volcanic eruptions per century whose aerosols cool Earth and the duration and extent of effusive basaltic volcanic eruptions that warm Earth (Figure 9). It typically takes changes in volcanism lasting for more than one thousand years to warm the whole ocean out of an ice age [*Ward*, 2016].

Recognizing that heat and electromagnetic radiation travel through matter and through air and space as frequency and amplitude has profound effects on other important issues in physics.

Reflection of light is widely observed and typically explained in terms of wave equations. We will need to think more deeply about how frequencies in air interact with the surface of matter. As we look around us, sunlight appears to increase the intensity (amplitude of oscillation) of the frequency of oscillation forming the color of each molecule that we can see. It is this amplitude and frequency that causes resonance in the cones of our eyes, allowing us to see that molecule. No reflection appears to be involved. In the case of a smooth water surface or a silvered mirror, however, reflection seems more likely. Is it, or is this a limiting case of refraction?

An electric field oscillating at some frequency induces a magnetic field oscillating at the same frequency as the electric field and perpendicularly to it, which in turn induces an oscillating electric field, and so on, forming a propagating electromagnetic field. *Maxwell's* [1873] equations for electromagnetism calculate that the velocity of a disturbance propagating through this field is equal to the reciprocal of the square root of the product of two physical constants: the vacuum permittivity (the resistance to forming an electric field) and the magnetic permeability (the ability to form a magnetic field). Thus, the velocity of light appears to be a function of how rapidly an electric field can induce a magnetic field, plus how rapidly a magnetic field can induce an electric field. This is a very short time. *Einstein* [1915] pointed out that the speed of light in a vacuum is the same for all observers, regardless of their relative motion or the motion of the source of the light. This implies that the speed of light is a property of the medium and that electromagnetism, therefore, may be the luminiferous aether that allows frequencies to be propagated by line of sight through air and space. We know that this type of luminiferous aether, an electromagnetic field, exists and that it is the oscillation of charge that allows it to exist.

Electromagnetic frequencies appear to travel by line of sight, but we know that in the immediate presence of matter, they can be refracted, causing radio signals, for example, to be bent around topography. *Einstein's* [1915] theory of general relativity predicted that light from distant starts would be deflected by Sun's gravitational field. *Eddington's* [1920] observations during an eclipse in 1919 seemed to verify this prediction. What role do you supposed diffraction played in the measured deflection?

The only way to decrease or increase the amplitude of oscillation of these frictionless atomic oscillators is via resonance. Just as changes in air pressure enable transport of resonant frequencies between identical tuning forks in air, changes in the electromagnetic field enable transport of resonant frequencies between molecules separated by air or space. This is what Einstein called "spooky action at a distance" since we cannot see the frequencies traveling in between. Every molecule that we see is oscillating at some frequency (color) that causes molecules in our eyes to resonate at that same frequency. Spooky action is simply a physical property of electromagnetic radiation. In quantum mechanics, the concept of quantum entanglement has been developed mathematically in great detail, seeking to describe spooky action while thinking in terms of wave-particle duality. We should look more carefully at the mathematics of quantum entanglement to determine how relevant these equations are to physical reality.

Based on observations of the cosmic microwave background by the Planck spacecraft (2009 to 2013) and the standard model of cosmology, the total mass-energy reservoir of the Universe is thought to contain 4.9% ordinary matter, 26.8% dark matter, and 68.3% dark energy. Dark simply means that we cannot see it but we think we see its effects. We cannot see electromagnetic radiation until it interacts with matter. Since Earth-bound observers can detect less than 5×10^{-8} % of Sun's radiation field, there must be a lot of dark energy in our Solar System being radiated by Sun.

From the blue line in Figure 2, it is obvious that when matter cools to temperatures close to absolute zero, it only radiates, and therefore only absorbs and resonates with radiation in the far infrared and microwave bands and that much higher frequencies in the near infrared, visible, and ultraviolet wavelengths would pass straight through, making the matter invisible or dark. In other words, dark matter contains no bonds that can resonate with near infrared, visible, ultraviolet radiation, X-rays, or gamma rays. The Planck spacecraft has sensitivity in the microwave and far-infrared and therefore is sensitive to radiation from very, very cold matter. What we currently call the Cosmic Microwave Background (CMB) has a mean thermal black body spectrum at a temperature of 2.72548±0.00057 K [*Fixsen*, 2009]. The map of the CMB could, therefore, be the map of dark matter, some of which is colder than others. As we approach absolute zero, rates of cooling become very, very slow because differences in amplitude of oscillation become very, very small. Thus differences in temperature probably reflect long differences in time.

The similarity between Newton's law of gravity and Coulomb's law has long been noted. Could gravity simply result from the minuscule force of attraction (Figure 1) per oscillator at large distance times very large amounts of mass—extremely large numbers of oscillators?

15. Conclusions

Thermal energy is the oscillation of all the degrees of freedom of all the bonds that hold matter together. Thermal energy equals the Planck constant (h) times the frequency of oscillation (ν): $E=h\nu$. This broad spectrum of oscillations on the surface of radiating matter, induce a broad spectrum of electromagnetic radiation where each frequency (color) propagates through air and space without interacting with any other frequency and where intensity (amplitude), initially determined by the temperature of the radiating matter, decreases with the square of the distance travelled. It makes no physical sense to add frequencies of radiation (light) together because they all coexist without interaction. Therefore it makes no physical sense to add thermal energies together.

Since $E=h\nu$, then the energy of ultraviolet-B radiation at 967 THz (310 nm) reaching Earth when ozone is depleted is 48 times more energetic, 48 times "hotter," than ultraviolet radiation absorbed most strongly by carbon dioxide around 20.1 THz (14,900 nm). The higher the frequency, the higher the energy, the higher the temperature will be raised of the absorbing body. Temperature results from a very broad spectrum of these oscillations. Carbon dioxide absorbs less than 10% of the low-energy infrared frequencies emitted by Earth and makes up only 0.04% of the molecules in air. Carbon dioxide and other greenhouse gases do not absorb enough energy (heat) to be a major contributor to global warming. Current climate models do not calculate thermal energy correctly.

Ultraviolet-B is the highest frequency, highest energy, "hottest" solar radiation to reach the lower stratosphere where it is normally absorbed to dissociate ozone in the ozone layer. When ozone is depleted, more of this radiation is observed to reach Earth increasing your risk of sunburn and skin cancer. Ozone depletion caused by manufactured CFC gases led to global warming from 1970 to 1998. Ozone depletion caused by an exceptional effusive eruption of basaltic lava in Iceland from August 2014 to February 2015 caused 2015 to be the hottest year on record and 2016 is highly likely to be even hotter. Temperature increases caused by this eruption should begin to subside in 2017, however. Voluminous eruptions of basaltic lavas have been contemporaneous with major global warming throughout Earth history.

Recognizing that thermal energy travels through air and space as frequencies and amplitudes, not as waves or particles, extends classical physics to microscopic levels in a physically intuitive way.

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