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Earth's Climate System and Humankind's Role

Honors Project Research Paper

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Global warming refers to the raising of a planet's atmospheric temperature on a global scale. This term is now used to describe one of humankind's greatest concerns because a significant increase in Earth's atmospheric temperature will lead to significant changes in earth's environment (Kraljic 19). Most of these changes will create unfavorable conditions for modern human society because much of today's society is dependent upon a stable climate system. Unfortunately, the more we learn, the less likely it seems that a stable climate system will be in humankind's long term future. Recent scientific investigations suggest that since the industrial revolution, certain anthropogenic activities may be having an effect on Earth's climate system and could be contributing to global warming. These activities have resulted from advancing human technology and increasing global population. The consequence is that humans have become a factor in Earth's global climate system. Further studies of this system will help us to make conclusions about humankind's role in Earth's climate system and estimate if there is anything we can do to engineer matters in our favor.

Global climate is a complex, interdependent system consisting of many interrelated processes. A global climate system is generally based upon the physical relationship between a planet and its star. Earth's rotation on its axis and interaction between the planet's atmosphere and oceans increases the level of complexity. The climate system is also affected by activities on land, such as volcanism. Climate systems are designed around negative and positive feedback mechanisms. These feedbacks are activated by a change. This change causes another change to occur, directly or indirectly. The process continues until a state of equilibrium is established (Houghton 162). Since our solar system is dynamic, states of equilibrium are rarely achieved for long durations. As a result, all components involved in this interdependent system affect the final product, our current climatic status.

The entire process begins at the Sun. The Sun emits electromagnetic radiation as it undergoes nuclear reactions. The intensity is greatest in the visible region of the electromagnetic spectrum. Strong emission also occurs in the ultraviolet and infrared regions. This radiation travels spherically outward from the Sun. The very small portion of this radiation, that is received by the Earth, is the source of energy for our climate system.

The balance between the amount of radiation received and the amount radiated back into outer space is called the global radiation budget. It is the central component of Earth's current climatic conditions. Our Sun's radiative output, called flux (**F**), defines the amount of radiation that is available for Earth's initial absorption. This initial absorption is also dependent on Earth's cross sectional area which is accounted for by its radius, **a**.

Like all stars, the Sun has evolved from its birth and will continue to evolve until its death. As a result, the Sun's flux varies with time. This is one of the main reasons why Earth's climate has changed significantly over geological time (Allegre 70). It is also a reason why Earth's climate system will continue to change.

Other factors that are important to the amount of radiation Earth receives are its distance from the source of radiation, the Sun, and its reflective quality. Any form of electromagnetic radiation will diminish in intensity as the inverse square of the distance. Therefore, our distance from the Sun, **R**, contributes strongly to the amount of radiation available to Earth. Once the Sun's radiation reaches Earth, a portion of it is reflected back into outer space, due to the Earth's reflectivity, its albedo. The albedo, **A**, is a factor ranging from 0 to 1 in which 1 represents full reflection and 0 represents full absorption.

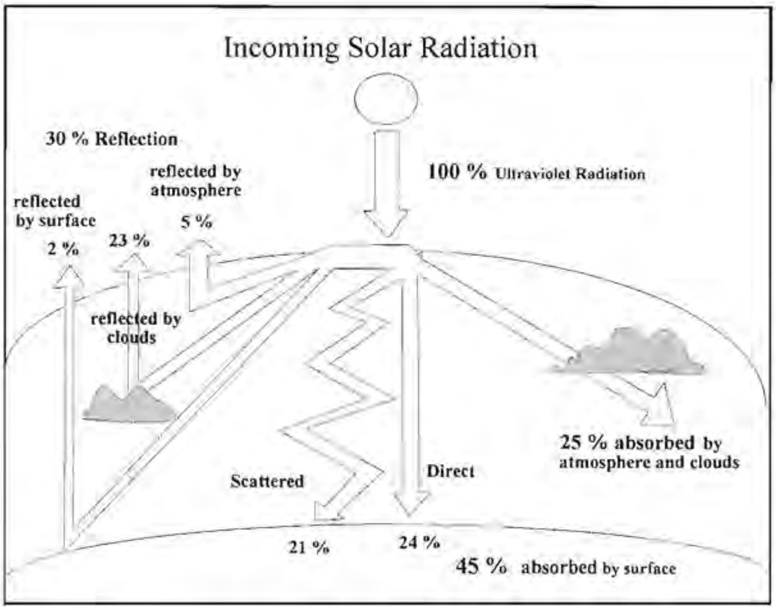
The equation below, which includes these previously mentioned factors, uses the Stefan-Boltzmann constant, σ, to relate **F** to the effective temperature, $\mathbf{T_e}$. This equation balances the radiation initially absorbed by a planet with the radiation that the planet eventually emits (Houghton 2). When this condition is met, a state of radiative equilibrium is established.

$$4\pi a^2 \sigma T_e^4 = \pi a^2 (1-A)\frac{F}{R^2}$$

When radiative equilibrium is achieved, the effective temperature ($\mathbf{T_e}$) should be equal to Earth's surface temperature. The Earth is nearly in radiative equilibrium with the Sun, yet the effective and the surface temperatures differ. The $\mathbf{T_e}$ for Earth is 256 K, but the measured temperature at Earth's surface is 280K. This difference, in temperature values, is caused by Earth's atmosphere. Absorbed radiation becomes temporarily trapped within Earth's atmosphere. While there, this radiation becomes the energy that drives our climate system. The mechanisms involved in the trapping of the radiation and its emittance into outer space are the more complicated aspects of our climate system.

The radiation from the Sun that plays a role in our climate system is in the ultraviolet region of the electromagnetic spectrum. Ultraviolet radiation, UV rays, is produced by the transitions of outer electrons and thermal sources such as our Sun (Halliday 41). Since Earth's albedo (**A**) is about 0.30, 30% of the ultraviolet radiation that the Earth receives is almost immediately reflected back into space. Twenty-three percent (23%) of the radiation is reflected by Earth's $\mathbf{H_2O}$ clouds, which usually cover half of the surface. The other 7% is reflected back into space by the atmosphere and the ground. This radiation never contributes to Earth's warming processes.

The remaining 70% of the radiation does play a part in the climate system. It is absorbed by the atmosphere and the surface. Twenty-two percent (22%) of the incoming UV rays are absorbed directly by the atmosphere and clouds. As a result, the other 45% of the incoming UV rays are absorbed by the surface. Twenty-one percent (21%) of the UV rays are scattered to the surface by the atmosphere and clouds, while 24% reaches the surface directly.



At the surface, the energy from these UV rays is radiated by the ground in the form of infrared radiation, IR rays. Infrared radiation, usually referred to as thermal radiation, is emitted by atoms and molecules when they change their rotational or vibrational motion. This change in the internal energy of the emitting object is observed as a change in the internal energy of the observing object (Halliday 41). Thermal radiation is an important means of energy transfer. This energy heats our planet and fuels our climate system.

Thermal energy is transported within the atmosphere through a convective system of general circulation. On a yearly basis, Earth receives more radiation at the equator than in the mid-latitudes. Earth's polar regions receive the least amount of radiation. This uneven distribution of radiation is due to a changing incident angle to the surface of the incoming radiation. This variation occurs with respect to latitude due to Earth's spherical shape. When the incident angle is 90°, the radiation strikes the surface directly. When this angle is less than 90°, the radiation is spread over a larger area which distributes less energy per area. These rays also travel a longer path through the atmosphere which increases the amount of scattering and absorption.

The laws of thermodynamics, specifically the first law, dictate that the more energetic equatorial region must come into a state of equilibrium with the less energetic polar regions. The warmer air, at the equator, expands and rises. When this occurs, the colder air rushes in to replace it so as to establish a state of equilibrium. This differential heating of the Earth by the Sun creates a global circulation of warm air masses from the equator to the poles and cold air masses from the poles to the equator.

Since the atmosphere is not physically bound to the Earth like the land and oceans, general atmospheric circulation has its own dynamics. This becomes evident when air masses travel either to the poles or the equator. At any point on the Earth, the surface has the same angular velocity because the entire planet will complete one rotation per day. Yet, as the latitudinal positions vary, so does the translational velocity, **v**. This is true because **v** is dependent on the distance that is traversed (**v** = **d**istance / time) as opposed to the angular velocity which is dependent on the angle that is traversed. While the angular speed remains constant at all latitudes (360°/day), the translational distance traversed is smallest near the poles and greatest at the equator. The surface's velocity is 1,036 miles/hr or 463 m/s at the equator. At 45° latitude the surface's velocity is 329 m/s. Near the poles it is almost 0 m/s. The distance traversed decreases as an air mass travels to the poles. Therefore, as an air mass travels along a line of longitude and crosses latitudes, its **v** deviates from that of the surface's. As a result, the air mass experiences an acceleration with respect to the ground below. This acceleration will have a positive value during poleward travel and a negative value, deceleration, during equatorward travel.

This acceleration is the reason why an air mass travelling toward one of the poles will move to the east in relation to the planet's surface. The opposite, a move to the west, will be observed if the air mass is travelling to the equator. Consequently, when air rushes to a central point, such as warm air to a cold center, a cyclic motion occurs. These air movements cause events, such as hurricanes, to spin in a counter-clockwise direction in the Northern Hemisphere and a clockwise direction in the Southern Hemisphere.

Since the air mass experiences an acceleration with respect to the surface, Newton's second law (**F** = **m a**) dictates that there must be a force present. This fictional force is called the Corlois force. The Corlois force is a significant factor for global wind currents. As air moves throughout the atmosphere driven by temperature differences, the warmer air will rise and the colder air will sink. Because colder air is heading toward the equator, it experiences a deceleration. This deceleration causes cold air masses to travel from east to west which is in the direction of the Corlois force. This force creates easterly winds in both hemispheres. These easterly winds will be at the surface because that is where the cold air has sunk to. At the same time, the warmer air experiences an acceleration as it travels toward the poles. This warm air movement creates westerly currents. These westerlies are aloft because the warm air has risen (Bonner 118).

General circulation between the poles and the equator also creates cells of flowing air, called Hadley cells, that are superposed on the westerlies. These cells of flowing air churn warm air toward the poles over cool air toward the equator. Hadley cells move much slower than their easterly and westerly components (Bonner 117). With slower velocity, their acceleration is much less. This smaller value of **a** creates a weaker Corlois force, which allows these cells to move in a north/south direction. Therefore, one Hadley cell in each hemisphere should transport the excess heat in the equatorial region to the poles.

When the conservation of angular momentum (**L = M v r** = *constant*) is considered, the simple circulation system is complicated. The rate of change of the angular momentum is equal to the sums of the torques. Since there are no external torques being applied to the Earth/atmosphere system, the angular momentum remains constant(Bonner 118).

As a result of this conservation of angular momentum, one Hadley cell per hemisphere is not possible. To have constant angular momentum, an air mass that moves from the equator toward the poles would need to constantly be increasing its **v**, due to a decreasing **r**. Scientists saw that this was consistent with the acceleration associated with the Corlois force, yet the numbers did not agree with actual observations. At the equator, the air mass' **v** is 465 m/s. When it reaches 45° latitude, the distance from Earth's axis, **r,** has decreased to 0.707 of its original value. Since **M** is constant, **v** must increase to keep **L** constant. Therefore, **v** must now be 658 m/s while the surface's velocity is 329 m/s. This means that the air is moving 329 m/s with respect to the surface. These wind speeds are not possible because of their great instability to small disturbances from the zonal flow. The cells themselves break down in the zonal circulation. At low latitudes, the change in **r** is small. Therefore, it is only there where Hadley cells can form stably (Bonner 119).

The conservation of angular momentum also disrupts the surface easterlies and aloft westerlies. This is due to the effect of friction between the atmosphere and Earth's surface. This friction would produce a torque in which the atmosphere tends to slow down the Earth while the Earth tends to speed up the atmosphere. This does not exist because the atmosphere has nothing to hold onto while pushing the Earth. As a result, the air currents quickly reach equilibrium with the surface's velocity. Because of this, surface winds over the entire planet cannot exist.

Still, to maintain a constant average flow pattern in the atmosphere, there must be weaker westerlies and easterlies. These winds exist in the middle and higher latitudes in conjunction with a series of waves and vortices. These waves and vortices transfer heat to the poles in a rotating system that also transfers the westerly momentum to the easterlies (Bonner 119). From this dynamic system of general circulation, the excess radiation received by the equatorial region is redistributed to the rest of the atmosphere.

General circulation can change Earth's climate system by affecting the chemical composition of the atmosphere. A phenomena, called El Nino, affects CO_2 levels in the atmosphere through changes it creates in circulation patterns. Easterly winds in the equatorial Pacific weaken due to a shift in air pressure over the Pacific Ocean. When this occurs, the sea level rises in the eastern Pacific and lowers in the western Pacific. The equatorial, easterly winds drag ocean waters with them. This current is deflected by the Corlois Force, which moves the waters away from the equator and coastline. When the surface water is removed, colder, nutrient rich waters rise from below, are upwelled. This upwelling occurs in a region along the equator less than one hundred miles wide. Phytoplankton and other sea life thrive in the nutrient rich environment. Satellite images of chlorophyll levels confirm these increased populations. This increase in sea life activity leads to an decrease in the concentration of CO_2 in the ocean water. These decreased levels of CO_2 will cause the oceans to remove more CO_2 from the atmosphere (NOAA El Nino).

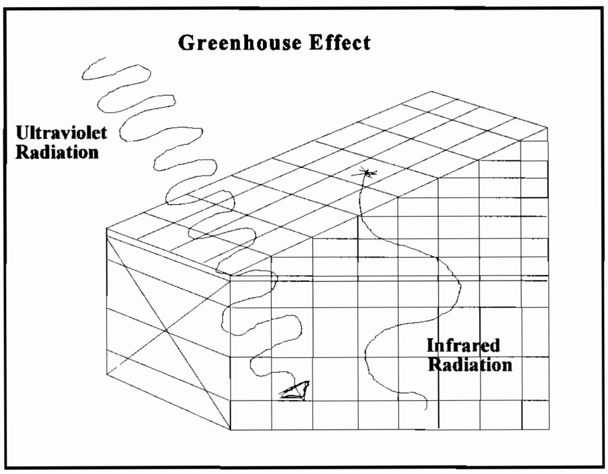
Our atmosphere is the physical host for Earth's climate system. It is the gaseous envelope that surrounds our planet with gases that trap heat and reflect solar radiation (Bonner 23). As a result, our atmosphere makes life possible on Earth. Earth's gravity is the force that retains our atmosphere. The force of gravity is scaled by the gravitational constant (**G**) and weakens with the inverse square of the distance. The change in $\mathbf{F_g}$ is minimal through the atmosphere because the change in **r** is minimal. Its strength is proportional to the product of the two masses which are the planet (**M**) and each molecule (**m**) of the gases in the atmosphere. Due to the gravitational field, Earth's atmosphere decreases in density with altitude, which causes atmospheric pressure to decrease with altitude as well. Both density and pressure drop off exponentially if an isothermal (constant temperature) atmosphere is assumed. The atmosphere is not isothermal, but this assumption makes for a good first estimate of density and pressure values with respect to altitude (Houghton 3). The atmosphere's structure of decreasing density and pressure with altitude is important to understanding how vertical structure affects our climate system.

$$F_g = G\frac{Mm}{r^2}$$

The majority of general circulation takes place in Earth's lower atmosphere. The lowest layer, called the Troposphere, is what we breathe and where nearly all of Earth's weather takes place, but the next layer is very important as well. This layer is called the Stratosphere. It interacts with the Troposphere and is important to the atmosphere's absorption of solar radiation. The Troposphere and the Stratosphere affect our climate system most. Still, all of Earth's atmosphere plays a role in the global radiation budget.

In the Troposphere, air temperature drops off steadily with increasing altitude, but in the Stratosphere which begins at 12 km of altitude, the temperature stabilizes and increases. This is due to the absorption of ultraviolet radiation, UV rays, from the sun by ozone, $\mathbf{O_3}$. The $\mathbf{O_3}$ later emits this radiation as infrared radiation, IR rays. The IR rays are then absorbed by carbon dioxide, $\mathbf{CO_2}$.

The atmosphere's ability to absorb and emit radiation is mainly dependent upon its gaseous composition. Certain gases absorb IR rays. This absorption of IR rays by a gas is called the Greenhouse Effect. This name is given to a gas's ability to absorb IR rays because on a global scale this phenomena acts very much like a greenhouse. As the energetic, shortwave UV rays enter Earth's atmosphere, the greenhouse gas is transparent to them in a manner similar to that of the glass ceiling of a greenhouse.



This transparency allows these rays to warm the Earth by ground and atmospheric absorption. When the thermal radiation tries to radiate back into space, the greenhouse gas becomes an opaque barrier to it, once again like the greenhouse's ceiling. Such is the case with $\mathbf{CO_2}$. As a result, it is considered one of Earth's chief greenhouse gases. In recent times, great concern has been given to the increasing levels of $\mathbf{CO_2}$ in the atmosphere. The $\mathbf{CO_2}$ level in our atmosphere has increased by more than 15% during the twentieth century (Bonner 26).

The quantity of $\mathbf{CO_2}$ in the atmosphere is regulated by the carbon cycle. This cycle distributes carbon between the atmosphere, the oceans, the ocean floors, the mantle, and the surface. The atmosphere and oceans preserve an equilibrium that is very important to CO_2 levels. The oceans remove CO_2 from the atmosphere by maintaining a certain concentration level of CO_2 in their salty waters. This concentration level varies as a function of the water's temperature. The colder the water, the greater the solubility of CO_2 in the oceans. Once in the water, the CO_2 is utilized by sea life for building their skeletal structures. Phytoplankton use the CO_2 and a calcium ion to manufacture their shells. These calcium ions wash into the oceans as a result of the weathering of silicate rocks on the surface. The silicate rocks are weathered by water when in the presence of CO_2. The use of CO_2 by sea life reduces the CO_2 level in the oceans. This allows the oceans to remove additional CO_2 from the atmosphere. When the phytoplankton and other sea life die, their carbonate structures sink to the ocean floor. The ocean floor is subducted into Earth's mantle as a result of plate tectonics. The bones of sea life, like the phytoplankton shells, go with the ocean floors into the mantle where they are metamorphosed back to silicate rocks and CO_2 gas. The CO_2 is returned to the atmosphere by the resulting volcanism (Caldeira and Rampino 96-99).

Earth's other chief greenhouse gas is H_2O vapor. Not as much is discussed about H_2O vapor levels in the atmosphere with respect to global warming, yet these levels are very important. H_2O vapor traps thermal radiation in a manner similar to CO_2, but H_2O vapor is involved with Earth's climate system in other ways as well. H_2O clouds reflect and scatter UV rays. In this manner, H_2O clouds act as a cooling mechanism but they also absorb some of the UV rays. Scientists have recently discovered that the amount of absorption that takes place in clouds may be greater than originally thought. Traditionally, it was believed that a cloud would absorb about 4% of the radiation that penetrated it. Now, it is believed that clouds may be absorbing around 15% of this radiation. The physical reason behind this is still unknown, but it seems to occur more readily when the cloud is located over a warm pool of liquid H_2O (AAAS).

Since variations in H_2O vapor levels could have a greater impact on the global radiation budget than do CO_2 levels, H_2O vapor may be the more important greenhouse gas. Worry over increasing CO_2 levels may be misdirected. Increasing H_2O vapor levels could contribute to global warming on a grander scale.

In the Mesosphere (52 - 80 km), the atmospheric layer above the Stratosphere, the temperature drops off even more than in the Troposphere. There is much less absorption of UV rays in this layer because there is much less O_3. At the same time, there is continued emission of IR rays from CO_2. This thermal radiation cools the Mesosphere significantly.

In the highest layer, the Thermosphere (80 - 115+ km), there is a tremendous increase in temperature due to UV absorption by atomic and molecular oxygen while there is much less IR emission from CO_2. There is some IR emission from nitric oxide, but it is a poor IR radiator compared to CO_2. At about 110 km in the Thermosphere, the air becomes too sparse to cool by thermal radiation. At this altitude, called the turbopause, the atmosphere continues to increase in temperature due to interaction with the solar wind, until it thins out to almost nothing. This vertical structure is unique to Earth's atmosphere, but other planets' atmospheres are still dominated by the same laws of physics, as following comparisons with the atmospheres of Mars and Venus will show.

Beyond studying Earth, we must look to space to find answers. The rest of our solar system provides us with other planets to study. Planetary exploration has allowed us to study the atmospheres of these other planets. The atmospheres of Venus and Mars are particularly important because they can be related to Earth's atmosphere, even though they differ greatly from it. Some obvious differences between the atmospheres of these three planets are average surface temperature, surface pressure, and chemical composition.

	Average Temperature (K)	Surface Pressure (atm)	Chemical Composition
Earth	280	1	N_2: 77%; O_2: 21%
Venus	730	90	CO_2 : 96%
Mars	220	0.007	CO_2 : 95%

Mars' size, about half that of Earth's, makes for a different atmosphere. In the gravitational equation, the acceleration due to gravity (**g**) is proportional to the planet's mass, **M**. Since Mars' mass (**m**) is less than Earth's, so is its **g**, 3.76 m/s^2, compared to Earth's, 9.8 m/s^2. Mars' smaller **m** also generates a smaller escape velocity which is the speed necessary to escape Mars' gravitational field. This makes it harder for Mars to hold on to the gases that makes up its atmosphere. As a result, Mars' atmosphere has a low density, which provides a very low surface pressure. This thin atmosphere does not provide Mars with the blanket of protection that Earth receives from its atmosphere. The atmosphere's low density is the main reason for Mars' cold surface temperature. Another reason is that Mars is 1.52 times further away from the Sun than Earth is. Even though Mars does have a lower albedo (0.15) and 95% of the atmosphere is $\mathbf{CO_2}$, its distance from the Sun and thin atmosphere keep Mars significantly colder than Earth.

$$V_{esc}=\sqrt{(2\frac{Gm}{r})}$$

In Mars' Troposphere, atmospheric dust, blown off the surface, helps to stabilize the temperature by absorbing sunlight. Because Mars has much less O_3, it does not have an equivalent to Earth's Stratosphere. As a result, the temperature continues to drop slowly in Mars' "Extended Troposphere." From just below 50 km to 110 km altitude, Mars' temperature holds steady due to the high level of CO_2 that allows the atmosphere to radiate energy readily. These mechanisms are rended ineffective above 110 km due to Mars' turbopause, as is the case in Earth's atmosphere. As the temperature increases, CO_2 is ionized in Mars' atmosphere due to interaction with the solar wind till about 150 km altitude. From here, Mars' atmosphere slowly thins out at a steady temperature that does not differ from night to day (Beatty and Chaikin 95).

Venus' atmosphere is almost the complete opposite of Mars'. Venus' atmosphere provides a scorching 730 K surface temperature with an atmosphere pressure 90 times greater than Earth's. Yet, Venus and Mars have much in common. Two characteristics that these planets' atmospheres share are their high levels of CO_2 and low levels of O_3. The high levels of CO_2 are a result of both planets' lack of liquid H_2O. Because they do not have liquid H_2O, which removes CO_2 from Earth's atmosphere, their atmospheres have become over abundant with CO_2. Since Venus is closer to the Sun and its atmosphere is much denser than Mars', it is more greatly affected by these high levels of CO_2. Tremendous amounts of thermal radiation are being trapped within Venus' atmosphere, by the CO_2. As a result, Venus is unique among these three planets because it is suffering from a massive Greenhouse Effect (Beatty and Chaikin 100).

This Greenhouse Effect is most prominent in the first 35 km of Venus' atmosphere. About the only thing that helps to stabilize this process is Venus' high albedo of 0.77. It stops 77% of the Sun's radiation from contributing to Venus' climate system. From 35 km to 48 km, the location of Venus' cloud cover bottom, the molecules are less densely packed than near the surface. This lower density causes this region to be partly transparent to IR rays. Better exchange of IR rays, with adjacent layers, allows for more radiative cooling to take place. This creates a shallower temperature gradient in this region. The low level of $\mathbf{O_3}$ allows the temperature to continue to fall off to about 200 K at 75 km altitude. At this point the very high level of $\mathbf{CO_2}$ stabilizes the temperature until the turbopause is reached. Venus' turbopause is located somewhat higher than Earth and Mars', which are at 110 km. In the upper atmosphere, the solar winds have a strong effect on the temperature. This is partly due to Venus being closest to the Sun. As a result, the temperature differs almost 200 K between night and day at these high altitudes (Beatty and Chaikin 95).

All three planets' atmospheres possess different vertical structures and chemical compositions while obeying the same basic principles. Comparison between these three planets illustrates how vertical structure and chemical composition are important to studying global warming and cooling mechanisms employed by an atmosphere to achieve radiative equilibrium with the solar radiation. By observing these principles in different environments, we can better understand the physical laws behind them. Information gained from planetary exploration could be the key that will unlock the mysteries of Earth's climate system.

Earth is comparable to Mars and Venus because they are all terrestrial planets, yet Earth is the only one that contains life as we know it. Life is composed of carbon (**C**). It estimated that the total mass of all organisms that ever lived on the Earth ranges from 2.5×10^{26} to 2.5×10^{33} g, which is 10% to 10^5 times Earth's mass. This suggests that the biosphere cannot be ignored as a player in the cycling of energy and matter through the carbon cycle (Caldeira and Rampino 103).

A hypothesis, named the Gaia Hypothesis, suggests that life actually maintains habitable conditions on Earth. It states that life actively regulates atmospheric composition and climate in the face of environmental challenges, like the Sun's changing flux. The "strong" version of this hypothesis proposes that life maintains optimum planetary conditions for living things. The "weak" version says that biological feedbacks and processes affect Earth's climate system (Caldeira and Rampino 103). It is already known that plant and sea life do affect the concentrations of certain gases in our atmosphere. As a result of the industrial revolution and a globally expanding population, humankind may also be included as a component in Earth's climate system.

Plant life removes CO_2 from the atmosphere during its respiratory cycle. This removal of CO_2 reduces the quantity of IR rays being trapped within Earth's atmosphere. Therefore, plant life acts as a cooling mechanism in our climate system. Recent depletion of the rainforests and old growth forests, on a global scale, decreases the amount of CO_2 that is removed from the atmosphere. This decrease leads to increased retention of IR rays by our atmosphere.

The greenhouse gas, methane (CH_4), affects an atmosphere's ability to absorb and emit radiation. CH_4 is 25 times more effective, than CO_2, at the absorption of IR rays. It is produced by bacteria that decompose organic matter in oxygen poor environments. Concentrations of CH_4 in the atmosphere have increased due to anthropogenic activity. Decomposing plant matter, in the stomachs of cattle and other livestock, has becomes a significant source of CH_4. Decaying vegetation in wet rice paddies is known to produce CH_4, as well. These elevated CH_4 emissions increase our atmosphere's ability to retain thermal radiation.

Sulfate aerosols have been found to create an anti-greenhouse effect. They come from industrial emissions of sulfur particles, about 0.1 microns in diameter, and phytoplankton emissions of dimethyl sulfide, $(CH_3)_2S$. These sulfate aerosols enhance a cloud's ability to reflect UV rays, by giving water droplets better condensation nuclei. This enhanced reflection by clouds increases Earth's albedo. An increase in Earth's albedo decreases the amount of radiation available to our climate system.

Ozone depletion, in the Stratosphere, is a chief environmental concern. Less stratospheric O_3 means more UV rays will reach Earth's surface. This increase in UV rays that reach Earth's surface is related to increased risk of health problems, like skin cancer, but there are also risks for the environment. A depletion of the Ozone Layer will certainly lead to an increase in the amount of radiation that is available for the surface to absorb. Increased UV ray absorption at the surface will cause an increase in surface temperature due to increased IR ray emission. This increase in surface temperature would affect all forms of life, especially plant life. What degree of change the surface environment would undergo is uncertain.

A depleted Ozone Layer will also eliminate Earth's Stratosphere. The presence of O_3 makes the Stratosphere different from the Troposphere. O_3 absorbs UV rays and emits IR rays which greenhouse gases, like CO_2, retain. Without O_3, atmospheric temperature would continue to drop off in the Stratosphere. Since temperature with respect to altitude affects general circulation, any change in the temperature at a certain altitude would change Earth's general circulation patterns. Different circulation patterns would lead to a different global climate system for Earth (NOAA Ozone Shield).

Concern over ozone depletion began with the discovery of a "hole" in the Ozone Layer over Antarctica. Satellite images have shown that the level of O_3 varies annually. The "hole" appears in the spring season of the Southern Hemisphere. Still, lower levels of $\mathbf{O_3}$ in the Stratosphere have been recorded throughout the atmosphere. A group of chemicals, chloroflorocarbons (**CFC**'s), is being held responsible for the stratospheric ozone depletion. **CFC**'s lose a chlorine ion when exposed to UV rays. This chlorine ion bonds with one of the oxygen atoms of $\mathbf{O_3}$, which reduces the $\mathbf{O_3}$ to $\mathbf{O_2}$. $\mathbf{O_2}$ does not have the strong UV absorption ability of $\mathbf{O_3}$.

CFC's are also dangerous to our climate system because they can retain 20,000 times as much IR rays as $\mathbf{CO_2}$ (Kraljic 63). The main sources of **CFC** emissions are leaking refrigerators and air conditioners and propellants in aerosol spray cans. **CFC**'s also come from the evaporation of industrial solvent and the production of plastic foams (Kraljic 107). They remain in the atmosphere for 65 to 110 years.

While ozone levels are decreasing in the Stratosphere, they are increasing at the surface. These increased levels come from emission of $\mathbf{O_3}$ by automobiles and industry. Higher levels of ozone at the surface increase the amount of UV ray absorption. This leads to increased amounts of IR ray emission at the surface, which increases surface temperature.

An excellent tool for studying planetary climate systems and these atmospheric radiative processes is satellite observation. Satellites can provide valuable information about the radiative processes that are currently occurring within a planet's atmosphere. Geostationary satellites are capable of continually photographing a specific region, while polar orbiting satellites can cover a planet from pole to pole (Ahrens 198). Satellite images are created, on a global scale, at various bands of the electromagnetic spectrum. These images are used to record levels of radiative intensity with respect to positions in the atmosphere or on the surface.

An image's resolution is dependent on the number of pixels it contains. Each pixel is a separate bit of data. For these images, the data in each pixel is representative of radiation intensities. The pixels can be manipulated through various methods to retrieve as much information as possible from one image. The pixels are composed as an image by setting them to certain colors with respect to their values. These false color schemes are called palettes. Comparisons between images, that measure radiation intensities at different wavelengths, show where different forms of radiation are being emitted from an atmosphere. These images give scientists information about actual radiation conditions.

Current images can be obtained through several file transfer sites (FTP) on the Internet. These images are usually taken at visible and infrared wavelengths. There are also images available that record water vapor levels. Image processing programs, such as ***NIH Image***, ***Browser***, and ***Voyager View***, can also be obtained through Internet. Greater detail can be extracted from these images by utilizing techniques, like enhancing contrast, and by applying certain palettes. The infrared images responded well to an inverted, "20 Color" palette and the "Fire 1" palette, with proper thresholding. The water vapor images showed better contrast with the "20 Color" palette.

Information obtained through processing of such images help scientists to design better numerical models of climate systems. A numerical model uses differential equations to relate many variables as they change with respect to time and one another. Current models illustrate some of the basics of Earth climate system, yet they also display the level of unknown involved with climate systems.

Through further studies, which should include the study of other planetary climate systems, we can continue to learn more about Earth's global climate system. We can infer that life has made some impact on Earth's climate system throughout geological history but humankind's contribution to this impact is still uncertain. Development of modern technology and tremendous increase in global population have supplied humankind with the ability and capacity to have an impact on our global environment. Is humankind currently affecting the climate system of Earth? Are we taking the necessary steps toward reducing this possibility or does our current situation call for more drastic action? Answers to questions of this nature will assist humankind in addressing environmental concerns, such as global warming. As our knowledge increases, humankind should come to understand the role it plays and is capable of playing in Earth's global climate system.

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