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The Effect of Carbon Dioxide on Climate and on Milankovitch Time Scale (20kyr to 400kyr Cycle)

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ABSTRACT: *Climate change has in recent times been the focus of many researchers. As a result, several theories have been proposed and debated. The impact of Carbon dioxide (CO_2), the second most significant greenhouse gas, is majorly emphasized. The source of this gas has been attributed to natural and anthropogenic. This paper reviews the emission of CO_2 into the atmosphere and the impact on climate from all the possible sources globally. The literature reviewed included articles, bulletins, and books published on the global sources and impact of CO_2.Additionally, the review looked at the impact of CO_2 on a Milankovitch cyclicity. It is determined that naturalproductscannotbe controlled. However, the anthropogenic sources depending on global policies can be reduced to the barest minimum to help balance the atmospheric and continental uptakes. Overall, CO_2 level may impact climate and the Milankovitch cycle positively and negatively.*

KEYWORDS: *Carbon Dioxide, Climate Change, Greenhouse Gases, Milankovitch cycle*

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I. INTRODUCTION

The advent of several hypotheses on climate change and global warming in recent times have hadmanyresearchers directed their efforts and focus on theimpact of carbon dioxide (CO_2) of concentrations, and as well as its sensitivity. CO_2, the second most important greenhouse gas (Le Trent et al., 2007), can be produced from natural and anthropogenic sources. It has been postulatedthat concentrations CO_2 have grown beyond the pre-industrial and agricultural age of about 280 parts per million by volume (ppm_v) in the atmosphere (Bigg, 1996) but has varied through time (figure 1). It is evident in figure 1 that, the fluctuations in CO_2 levels are in phase with temperature. Thisis indicated as a rise in CO_2 level implies a rise in Temperature. This paper reviews the importance of CO_2 and further discusses the global impact concentrations of CO_2 may have on climate and the Milankovitch timescales.

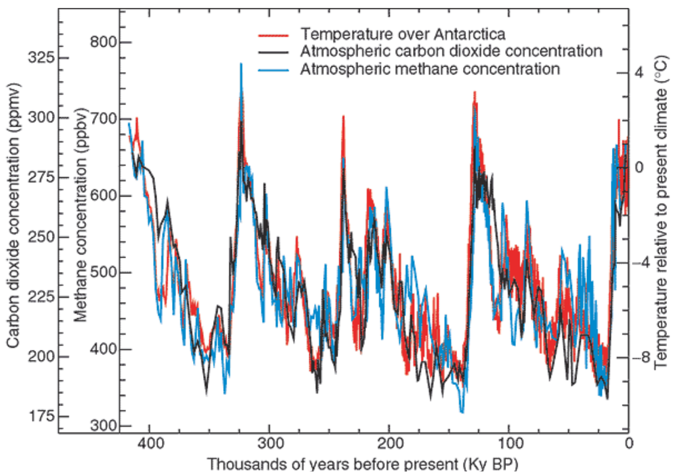

Figure 1: Variation in concentrations Carbon dioxide, Temperature and methane through time (Petit et al.,1999)

Carbon Dioxide

Carbon dioxide in an inorganic compound with a chemical formula CO_2 (CO_2 exist as two oxygen molecules in a covalent bonded with a carbon molecule) and forms part of the many gases in the earth's atmosphere. Shakhashiri(2002)asserts that the concentration of CO_2 at 0.033% or 330 parts per million is distributed uniformly in the earth's atmosphere. Though a component of the atmosphere, they are also dissolved in water (ocean), with a solubility of nearly 90cm^3 of CO_2 per 100mLof water. The properties CO2 in conjunction with changes in temperature and pressure makes it possible to exist in phases as figure 2.

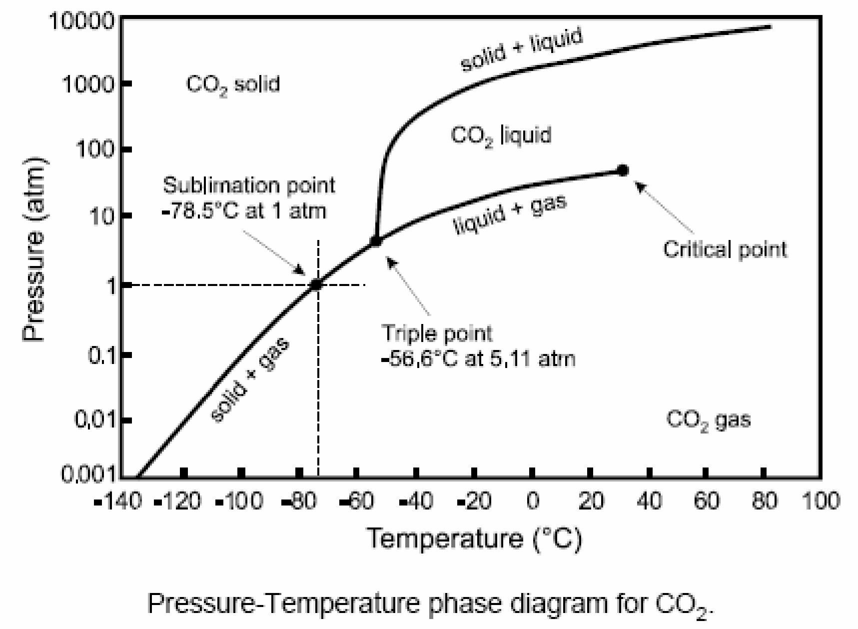

Figure 2: Phase diagram of carbon dioxide (after Shakhashiri, 2002)

They are produced naturally and anthropogenically. Some natural sources among others are organic matter decomposition, plant and animal respiration, ocean and atmosphere interaction, and volcanic eruption, whereas most anthropogenic sources are mainly human activities such as the burning of fossil fuel(most important), industrialization,deforestation /desertification, dust,and aerosols. Figure 3 and 4 illustrate some anthropogenic contribution of CO_2 globally and in the USA.

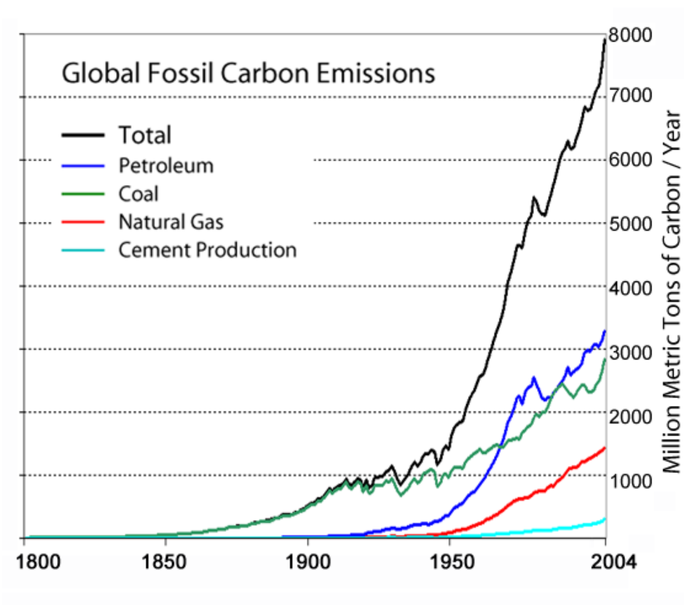

Figure 3: Global anthropogenic emissions of carbon

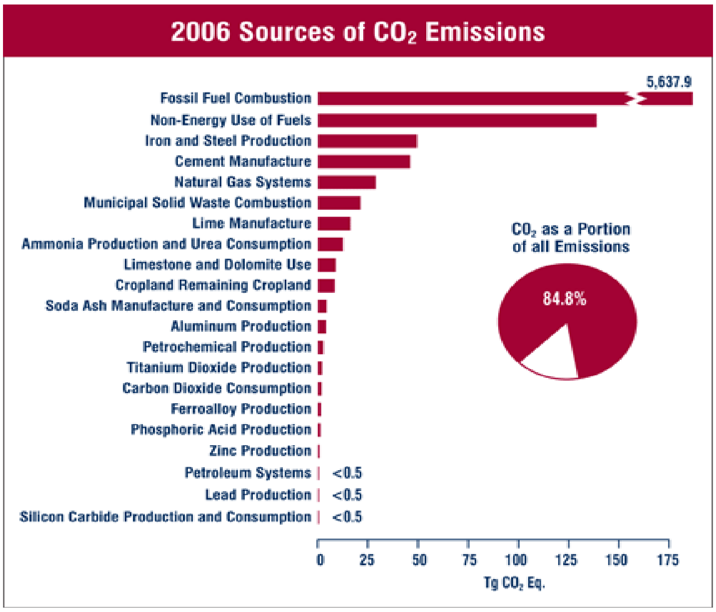

Figure 4: sources of emission of CO_2 % in the USA (U.S. Greenhouse Gas Emissions Inventory)

Though the increase in the concentrations of CO_2 is of graveconcernregarding temperature change (figure1), it has significant uses applicable to human's existence. CO_2 is useful in the production of soft drinks (soda), winemakingand food (pop rocks). It is also useful in pneumatic systems, lasers, fire extinguishers, welding, caffeine removals, dry cleaning, pharmaceuticals,and other chemical processing. Other uses are biological (photosynthesis and plant growth), and oil and coal bed methane recovery.

Climate

Ruddiman(2001), defines climate asthe average measure of long termchanges in conditions such as temperatures, snowfall or rainfall quantities, winds, snow and ice cover over a region. These measures are enshrined in the air, water, ice, land,and vegetation of the earth surface, thus dubbed the significant components of the climate system (Ruddiman, 2001). Within these components are the procedures for instance precipitation, evaporation and winds.

The external (natural) influences on these components resulting in changes in the climate constituent are changes in plate tectonics, the Earth's orbit, sun's strengthandalso the anthropogenic (Ruddiman, 2001). These changes result in the variability in solar radiation, aerosols, greenhouse gases,and the global carbon cycle. They ultimately result in the change of the climate system. The interactions are as expressed in figure 5 while the energy balance pattern based on these is shown in figure 6. The responses to these influences on climate interactions take several years to impact the climate; their response ismeasuredregarding the alteration feedbacks. They are either positive or negative, with the former expressed as amplification and the latter suppression responses by the climate system. Figure 7 show models of both natural and anthropogenic forcing leading climate change.

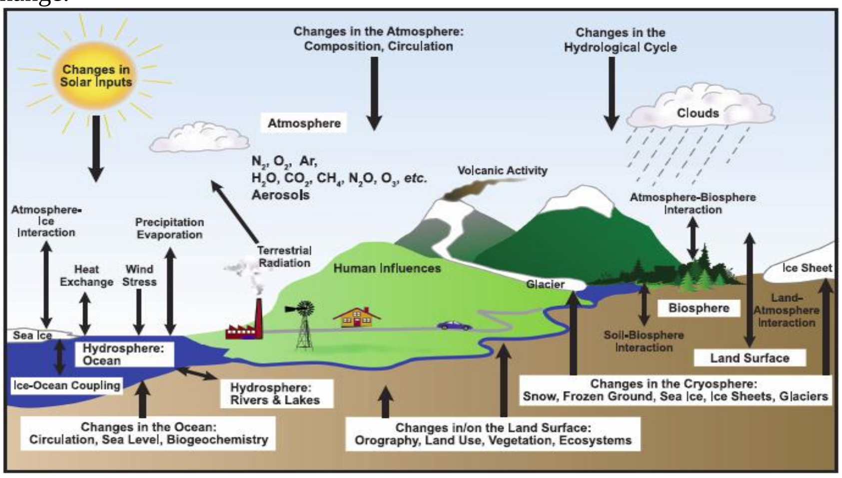

Figure 5: The processes and interactions of climate components (Le Trent et al., 2007)

Natural forcingfactorson climate

Climate variation measurements are known as the responses, which are due to the long term interaction of the forcing factors operating within a sophisticated atmosphere, earth, ocean, ice and land surface(Ruddiman, 2001). Thus, measurable changes are due to the impact of the forcing drivers (external or internal).The forcing factors are categorized into 3 or 4, depending on the nature of the investigations. They are a tectonic process, Earth-orbital changes, changes in the strength of the sun and anthropogenic forcing (Ruddiman, 2001). These processes are characterized by external and internal forcing factors. External forcing factors are Galactic variations, Orbital variations (Obliquity, Eccentricity, and Precession - Milankovitch) and solar variations. Some internal forcing is Orogeny, Epeirogeny, Volcanic activity, Ocean and Atmospherecirculation. Additional, these processes are classified as radiative and non-radiative forcing (figures 5 and 6).

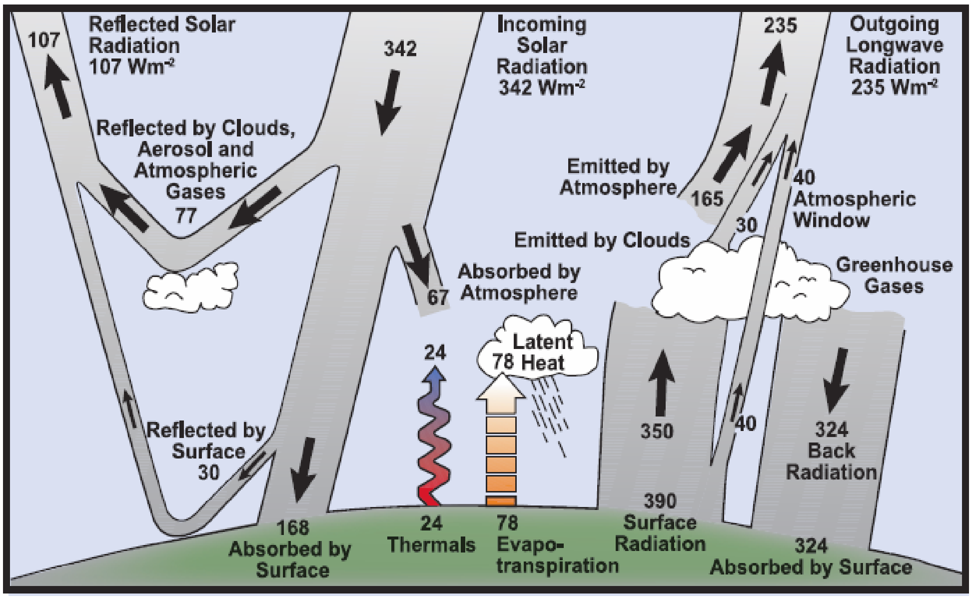

Figure 6: Estimates of global mean energy balance and the Earth's annual (after Kiehl and Trenberth, 1997)

Under broad classification to differentiate the sources, these forcing factors can be characterized as naturaland non–natural causes of climate change (Burroughs, 2007). The following are natural initiators of changes in the climate system; long term atmosphere and ocean interactions, ocean currents, volcanoes, sunspots,and solar activity, Tidal forces, orbital variations, continental drift (Plate tectonics) and changes in atmospheric composition (figure7).

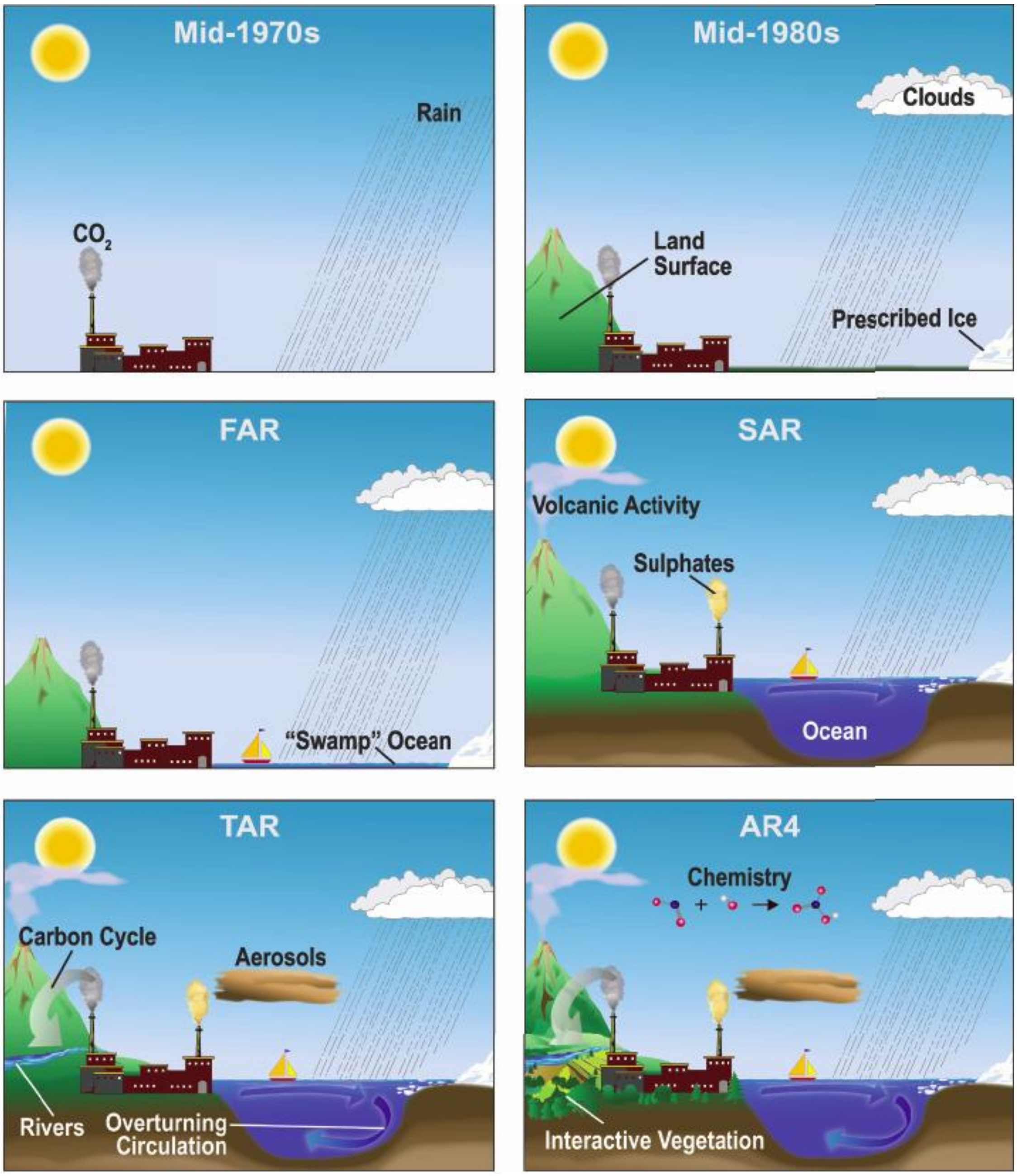

Figure 7: Models of climate change (Le Trent et al., 2007)

The process through which the climate is alteredon alongtime scale

1. Atmosphere and ocean interaction – the alteration of the climate through interaction these agents is due to the long-term fluctuations in their circulations. The short term effect is driven by the atmosphere whereas the long term is by the ocean.The atmospheres circulation influences changes in the ocean temperatures, the reverse holds for the atmosphere,but the ocean's control overshadows that of the atmosphere. Some critical changes that best explains this pattern are the periodic oscillations between warm and cold temperature events (ENSO).
2. Ocean current- the transfer of energy from low latitudes to high latitudes are activities of ocean currents (circulation). Thus any changes or reversal in this pattern has significant climatic implications. The circulations of the oceans are related to continent distribution in the geologic past. Therefore large scale ocean circulations can change the climate.
3. Volcanoes- activities of volcanoes depending on the gases (sulphur dioxide, carbon dioxide) and dustemittedinto the atmosphere impacts the climate with either positive or negative feedback and subsequently altering the climate.Sulphur dioxide in the atmosphere is converted to sulphuric acid aerosols; they spread out, absorbs the incoming sunlight, resulting in less amount of solar radiation reaching the earth

surface. The inference is cooling conditions over the earth, which may exist for several years. An example is the Pinatubo eruptions which caused are reductions in solar energy to the Earth's by 3 to 4 watts per square meter.

Similarly, high amounts of carbon dioxides injected into the atmosphere through the process impacts climate system. The resulting effectis increased in temperatures.

4. Tidal forces–Climate change is linked to tidal forces through changes in the movements that exist with the atmosphere, Earth's crust,and the oceans. The basic concept with tidal forces effect is best explained with the impact gravitational forces being exerted on the Earth's surface as it orbits around the sun. Tidal forcing,due to the planetary motions also impacts the sun's circulation and solar activities, thisresults in either the slowing down or speeding up the Earth's movement, which releases tidal energy and overturns circulation, thus receding effect of the moon from the Earth at the rate of 4 centimeters per year.
5. Orbital variations – The continuous gravitational connections with the moon and other planets influence the Earth's trajectory all-around the sun. This occurs on a longer time scale. The resulting effectsare termed as the cyclical variations in orbital eccentricity, obliquity,and precession. Eccentricity has periods of 95, 125 and 400 thousand years, Obliquity (variations in the tilt of the Earth axis) has 41 thousand year cycles, and precession is with 19, 22 and 24 thousand year periodicity (figure 8).These changes lead to substantial changes in the Earth's climatic systems.

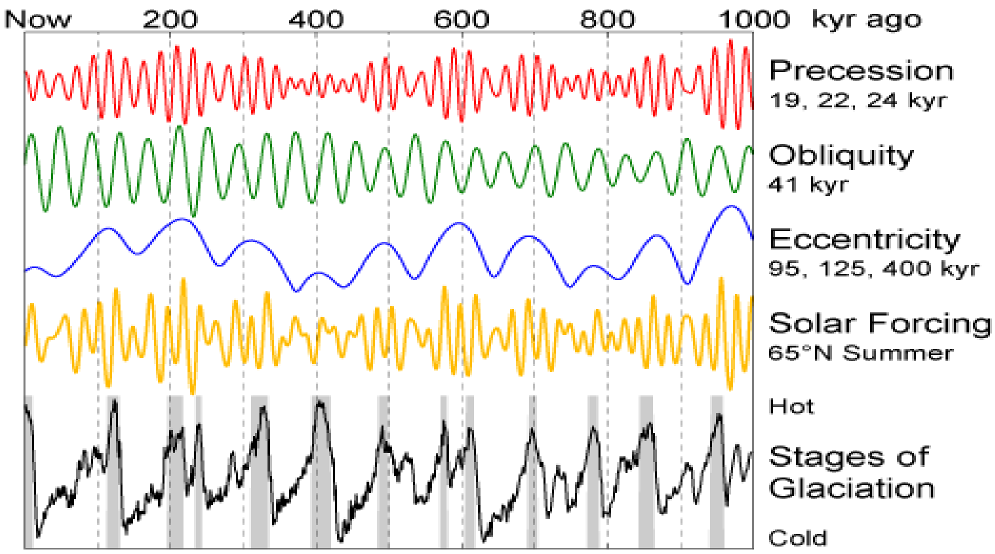

Figure: 8the Milankovitch cycle (afterhttp://earthobservatory.nasa.gov/Features/Paleoclimatology_Evidence/)

6. Changes in atmospheric composition –variations in the concentrations of the atmospheric gases have considerable climatic implications. These gases under normal circumstance should balance with the other important forcing factors to generate a stable climate. Otherwise, an imbalance results in changes in climate. For example, CO_2 increases or decreases results in high or low temperatures respectively (Burroughs, 2007).

Anthropogenic forcingfactorson climate

The anthropogenic forcing factors consist of sources introduced (induced) or injected by activities of humans. These sources are categorized as greenhouse gas emissions (CO_2, CH_4), dust and aerosols, desertification and deforestation and ozone holes (figure 7).

The greenhouse gases are those gases within the atmosphere with the ability to absorb and emit radiation within the thermal infrared range. These are water vapor, carbon dioxide, methane, nitrous oxide, ozone, and chlorofluorocarbons. Thus, thegreenhouse gas emissions are gases injected into the atmosphere which leads to increasing the greenhouse effect. CO_2, which many monitoring records, and studies from ice-core data have indicated a rise of about 280 parts per million by volume (ppmv) during the pre-industrial period to about 380ppmv at present (figure 4)has altered the climate (Burroughs, 2007). The CO_2gases are essentially emitted through the burning of fossil fuels, and industrial usage of machinery (figure 4).

Similarly, CH_4 concentrations have been found to have increased from the pre-industrial levels of 700 parts per billion by volume (ppbv) to the present levels of about 1780 ppbv. This also impacts the Earth's climate. Additionally, other criticalgreenhousegases are on the increase (Burroughs, 2007). It is also believedthat the resulting of these gases since 1850 have generated radiative forcing of about 2.5 watts per square meters, of which CO2 contributes about 60%, CH_4 contributes 25 %, while the remainder is contributed by the othergreenhouse gases(Burroughs, 2007).

Dust and aerosol form the atmospheric particulates, though others exist. Their impact on the climate is dependent on the ability of the particulates to absorb,and reflector scatters radiation. These particulates are generated for example sulphur particulates from sulphur containing compounds contained in fossil fuels, sooty particulates from the burning of fossil and biofuels. Large concentrations of these particulates are introduced into the atmosphere through surface land uses (construction, mining, agriculture). These expose the land surface to winds and areraised into the atmosphere (Burroughs, 2007). This alters the amount of solar energy reaching the Earth's surface and subsequently altering the climate (cooling).

The climate also impacts desertification and deforestation. Deforestation can result in desertification; this leads to the exposure of the land, which increases the amount of dust in the atmosphere. Deforestation introduces addition CO_2 into the atmosphere due to the nonexistence of the trees/vegetations intake of CO_2.

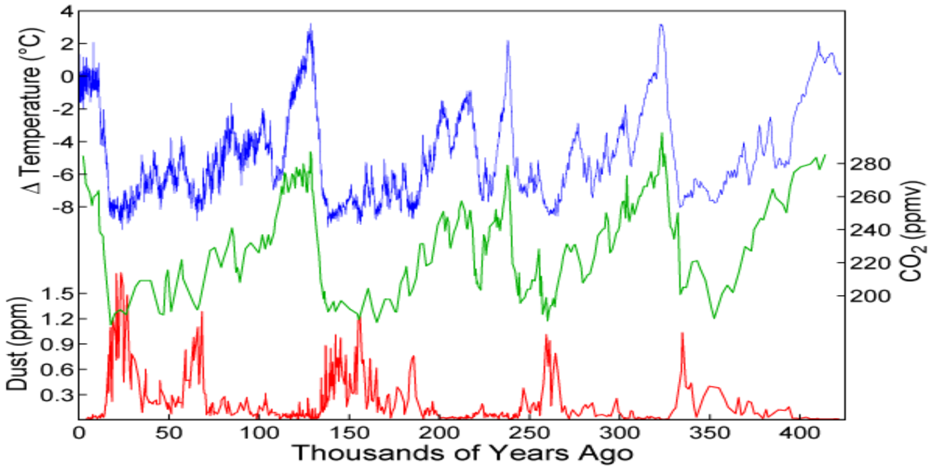

Figure: 9 Variations in Dust, CO_2,and Temperatures from 400kyrs to recent times (http://upload.wikimedia.org/wikipedia/commons/c/c2/Vostok-ice-core-petit.png)

Milankovitch Time Scale

This is a theory named after a Serbian astronomer Milutin Milankovitch (Ruddiman, 2001), whothrough the use of equations gravitational pull of other planets and moon calculated the slow variations in the earth's orbital movements (Burroughs, 2007).

Ruddiman (2001), defines the Milankovitch theory as a "the theory that orbitally controlled fluctuations in high-latitude solar radiation (insolation) during summer control the size of ice sheets through their effect on melting."

The theory states axial tilt is small (large latitudinal temperature gradient), large eccentricity and the occurrence of perihelion during the Northern Hemisphere winter which has warmer winters and colder summers, allows snow accumulation right through the summer months(Buchdahl,1999).Also, the amount of water vapor at high latitudes existing for snowfall increases because of the rise in a temperature gradient, which is also as a result of warmer winters and rises in general atmospheric circulations (Buchdahl, 1999).Milankovitch estimated climatic fluctuations over the last 450,000 years and described cold and warm periods (figure 10)

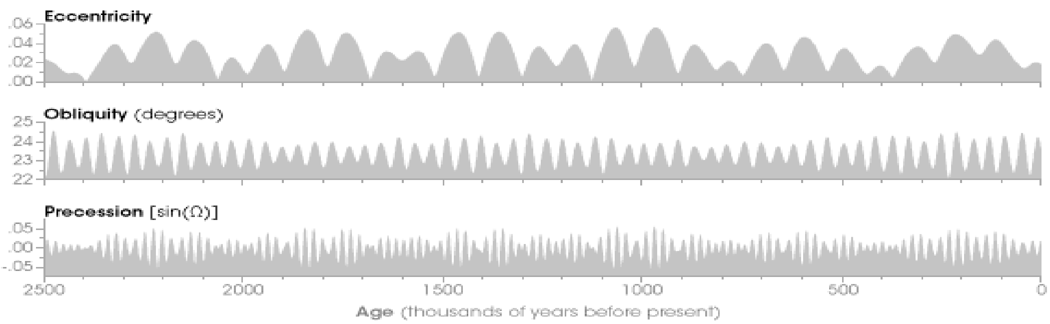

Figure 10 variations in Eccentricity, Obliquity,and Precession through time (http://www.ncdc.noaa.gov/paleo/milankovitch.html)

He determined that the earth "wobbles" in its orbit and the earth's seasons arecaused by its "tilt."Therefore, the strength of the season changes is dependent on the variations in the tilt of the earth. The three components modify these seasons;eccentricity (increasing the earth-sun distance at this aphelion position) of the orbital path around the sun, the precession effect, the position of the solstices in the annual orbit and obliquity. These components impact the incoming flux of solar radiation, subsequently affecting the temporal and spatial distribution of energy(Burroughs, 2007).Buchdahl, (1999), states that the climates system's energy budget is influenced by these changes, thus considered as the basis of changes in the climate over the time scale of 10^4 to 10^5.Buchdahl, (1999) further states that these changes be categorized as an external forcing mechanism to the climate system.

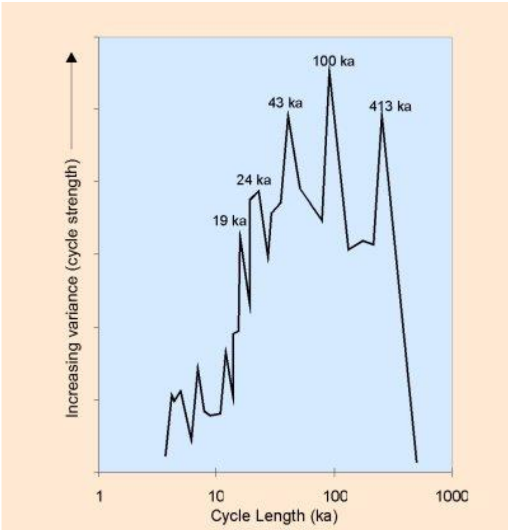

Figure 11: Orbital periodicities identified through spectral analysis (adapted from http://www.ace.mmu.ac.uk/resources/gcc/figures/2_1.html)

Several patterns exist in the eccentricity, axial tilt,and precession of the Earth's orbit.These patterns of periodicities (100,000, 43,000, 24,000 and 19,000 years) have been proven with long-term temperature proxy data and spectral analysis (figure 11) to correspond with the theoretical Milankovitch cycles nearly.

Obliquity

TheEarth rotates around the sun on its rotational axis. On this axis, the Earth is tilted at an angle concerning a perpendicular to the Earth's orbital plane. It is presently at an inclination of 23.4^o but has in the past oscillated between 22^o and 24.5^o. This is evident over a time period of 41,000 years, and this is termed as the Earth's Obliquity. These changes in the angle of tilt impacts latitudinal solar radiation distribution.

Though obliquity has no impact on the total received amount of solar radiation by Earth, the distribution of the insolation is impacted in space and time. Summer and winter insolation at higher latitudes increases and decreases respectively with increases in obliquity and subsequent increase in the amount of received solar radiation. Obliquity strength decrease from high to low latitudes, thus towards the low latitudes, obliquity changes have little impact.Accordingly, the latitudinal temperature gradient's strength is impacted by the changes in the Earth's axial tilt. This implies increases in the earth's tilt raises the annual amount of solar energy received at high latitudes, which reduces the latitudinal temperature gradient(Buchdahl, 1999).

Eccentricity

The orbital path of the Earth around the sun is elliptical(figure 12) instead of circular. The process is classified as the second orbital variation as the Earth rotates. Thisis termed as the eccentricity. Eccentricity is represented with the parameter 'e,'andis ascertained using the equation below, which is evaluatesthe two focal lengths, x,and y as shown in figure 12.

$e = \{ (x^2 - y^2)^{1/2} \} / x$

If the orbital path becomes circular, then the lengths x and ywill be equal, and that the value eccentricity from the equation will be 0, but the Earth's orbital eccentricity has been determining to vary from 0.005 (nearly circular) to 0.06 (markedly elliptical). The present eccentricity value is 0.018. This process exhibits two primary periodicities of approximately 96,000 and 413,000 years (Buchdahl, 1999).The total amount of solar radiation directed at the top of the Earths atmosphere is impacted by changes in eccentricity.About 30% differences in solar radiation arise between perihelion and aphelion when eccentricity is at maximum (Buchdahl, 1999).

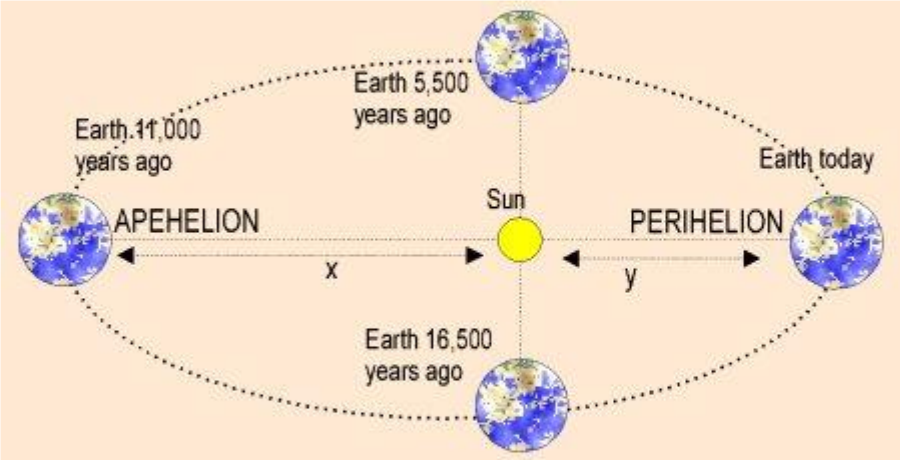

Figure 12: Earth's past and present orbital locations during the northern hemisphere winter (adapted from http://www.ace.mmu.ac.uk/resources/gcc/figures/2_1.html)

Precession

Precession is the third orbital variation known. The precessing of the Earth in an elliptical orbit around the sun is due to the gravitational interaction of the planetary bodies in the solar system. This process is termed as the precession of the equinoxes and impacts the seasonal intensities. Precession is categorized into two components:

- An axial precession – This occurs when the axis of rotation gyrate like a spinning top because the torques of the other planets are exertedon the Earth's equatorial bulge.
- An elliptical precession – This occurs when the elliptical orbit of the Earth itself rotates about one focus.

The combined impact of the two components describes the precession of the equinoxes with a period of 22,000 years. The precession splits into periods of 19,000 and 23,000 years because the term is modulated by eccentricity. Similar to obliquity, the total amount of solar energy received by the Earth is not impacted by precession. The impact is the distribution in the hemispheres over time. The summer solar radiation increases in the northern hemisphere when perihelion occurs in mid-June and Earth is tilted to the sun. On the other when perihelion occurs in December, solar insolation northern hemisphere will increase in winter. The solar radiation received on the Earth's surface is in changes direction in the opposite hemispheres (Buchdahl, 1999).

How climate change is measured

Analysis of tree rings (figure 13), sediment layers (figure 14), ice cores (figure 15), and corals(figure 16), are used to deduce early (past) climate conditions(Ruddiman, 2001). Thesedepending on characteristic climate conditions are made up annual layers which arecreatedeach layer. Thecharacteristicsclimate conditions translate the makeup into a chemical composition, color, texture, and thickness.

Figure 13:the Radial/cross-section from a giant sequoia log (Sequoiadendrongiganteum) http://www.koshland-science-museum.org/exhibitgcc/historical01.jsp

Through the analysis of tree rings (figure 13), long-term, quantitative temperature and precipitation records can be established (Ruddiman, 2001). Similarly, the thick light-colored layers in the core in figure 14 showextreme warm summers.

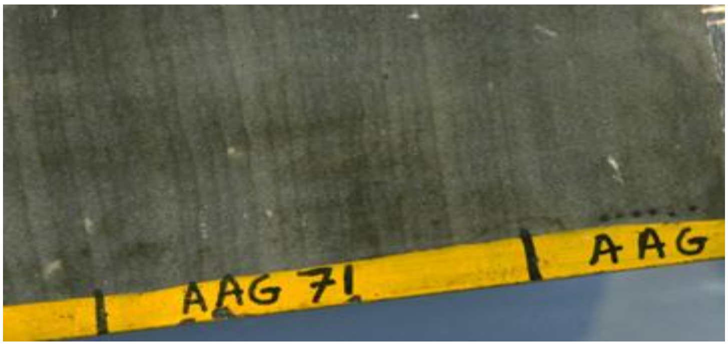

Figure 14: Sediment Cores from the Castile Formation(http://www.koshland-science-museum.org/exhibitgcc/historical01.jsp)

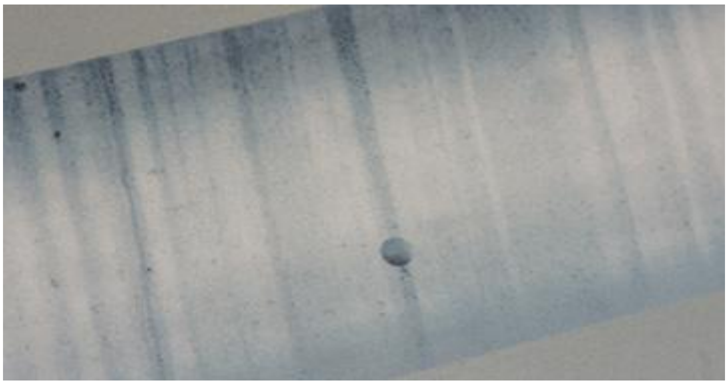

Figure 15: Ice Cores(http://www.koshland-science-museum.org/exhibitgcc/historical01.jsp)

Historical snowfalls are revealed via the thickness of the layers. The atmospheric composition of the past is also revealed through the analysis of the trapped air bubbles in the ice (figure 15). Year to year records of the tropical climates which go over into the past few centuries is gotten from corals growing near the ocean surface (figure 16). This also leaves annual growth bands similar totrees, which the living tissue is found only on the uppermost layer.

Instruments(temperature, wind, humidity sensors) of high resolution, precession are used in recent times to measure climate and its associated impacts. They expand globally than what is used in measuring the past.

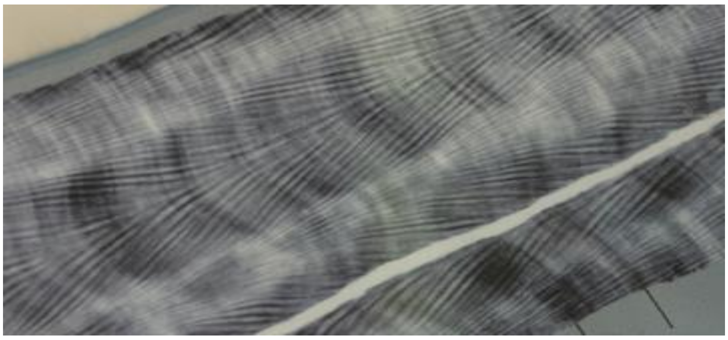

Figure 16: Coral Cores**(**http://www.koshland-science-museum.org/exhibitgcc/historical01.jsp)

Carbon dioxide impact on climate

A series of experiments using the present day conditions have been run by several scientiststounderstand the impacts of CO_2 levels on the Earth's climate. The levels of CO_2 modeled range between as low as 100 ppm and 1000 ppm. All experiments and analysis indicateaglobalrise in average temperatures with increasing CO_2. This is a non-linear relationship because,with a little change in lower end values of CO_2, the earth's temperature reacts strongly. Conversely, temperature reactions are much weaker at higher levels of CO_2, this due to the factor that, equilibrium is close to such high values. Low concentration of CO_2 enhances the coverage or the extent of sea ice and snow, thus with much snow cover, minute changes in CO_2 will have a huge impact on climate, and thereby altering the area of coverage of ice and snow over the Earth. Based on this background, the following can be inferred from the models of$CO_2$and the climate system(Ruddiman, 2001).

High CO_2 values reduce the extent of snow and Ice at the high latitudes; this is due to the resulting warming effect of the planet. Therefore positive feedbacks would be generated from only small areas. Small advances of snow or ice are generated when a substantial decrease in levels of CO_2occurs. The sensitivity of the climate system to changes in CO_2 under these conditions is much less.Additionally, when the atmosphere is saturated with CO_2, a rise impacts the climate system by back trapping radiation from the Earth's surface, but increases getto a point where further increases in CO_2 would have not much impact on the climate. Thus CO_2 saturation at higher CO_2 levels contributes to temperature rises which are slower.

Another factor is the water vapor feedback. A large amount of water vapor is heldinawarm atmosphere generated by high levels of CO_2 than cold atmosphere generated by low levels of CO_2. Thus, water vapor feedback on the temperature in warmer and higher CO_2 levels strengthens. There is a disparity between this condition and the "diminishing effect of the albedo-temperature feedback." It is therefore evidently clear that at high CO_2 levels in the atmosphere will impact the climate system with increases temperatures, and thus large sheet can exist, resulting in high temperatures at high latitudes. Overall changes in levels in CO_2 can impact the Earth's climate positively or negatively(Ruddiman, 2001).

Carbon dioxide impact on Milankovitch

The small cyclic changes in the earth orbits around the sun are termed as the Milankovitch cycle.This impacts the angle at which the earth relates to thesun and results in ice ages of the past million years preserved in the Earth's permanently trapped atmospheric gases (figure 8) in sediments, ices,and others. Figure 9 shows that CO_2 levels have varied through time with corresponding increases in temperature. Based on figures 8 and 9, it can be inferredthat the global climate change is dependent on these small orbital changes, which intend triggers the small amount of changes in solar radiation reaching the Earth's surface. Thisis linked to the Milankovitch cycle instead of the variability in the sun's output. Thisis confirmed with the ice ages in figure 8. Because the Milankovitch cycle impact is observed in climate records, any changes in the Earth's atmospheric composition that might cause changes in temperature intensity will impact the Milankovitch cycle; therefore with increases in CO_2 levels, the Milankovitch cycle would be impacted.

II. Conclusion

Although CO_2 has many good uses in industries. A typical example is the recent ideas and uses of CO_2insequestration in the oil industry.Thechanges in its levels (low or high) will impact the global climate. The natural production of CO_2cannotbe controlled. However,anthropogenic productions sources depending on policies of various governmentmayare reduced to the barest minimum to help balance the atmospheric and continental uptakes. Overall,depending on levelsof concentration, CO_2production mayimpact the climate and the Milankovitch cycle positively and negatively.

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