Climate Change Conundrum

What is Climate Change? Is it real to you or something conjured up by NASA scientists and members of the Intergovernmental Panel on Climate Change (IPCC)? Are you tired of hearing about *Green this* and *Eco that*? Is this talk of the gloom and doom in our future wearing on you and you do not want to hear anything more about Climate Change? Well I can relate, I am tired of the *Green this* and *Eco that,* greenwashing that I see as I research various building products. But, from what I have discovered in the process of doing the research for this paper on the *Climate Change Conundrum* there are changes coming our way and these changes may be serious, depending on how quickly and to what extent we as the inhabitants of Earth react.

I. Conundrum

Why am I claiming Climate Change is a conundrum? According to Wikipedia; a conundrum is a logical postulation that evades resolution, an intricate and difficult problem. With that in mind, let me share with you some of what I have learned about the science of Climate Change and you can decide for yourself whether this is an appropriate definition.

Consider the fact that for nearly 4 1/2 billion years the Earth **(Slide 1)** has been spinning on its axis, while orbiting around the Sun. Putting that timeline in perspective, if Earth's history were one 24 hour day, humanities evolution over the last 200,000 years is equivalent to the last 3.8 seconds of that day. During that long history, Earth has underwent numerous cyclic extremes of ice ages and subsequent interglacial warming's. How could that be, what causes these varying temperature cycles? That was the question pursued by many scientists during the 1800's. Finally, in the early to mid 1900's a Serbian named Milutin Milankovitch pulled it all together. It wasn't until the 1970's that scientists confirmed his work.

II. Climate Change Prior to the Industrial Revolution, before 1750

The Milankovitch Theory is an explanation of long term climate change. Milankovitch built his theory from previous work done by J.A. Adhemar and James Croll. Milankovitch, a mathematician, set out to develop a mathematical theory of Climate Change. His theory states that, "as the Earth travels through space orbiting the Sun, cyclical variations in three elements of Earth-Sun geometry combine to produce variations in the amount of solar energy that reaches Earth." These three elements are Eccentricity, Obliquity, and Precession.

Eccentricity describes the shape of Earth's orbit around the sun **(Slide 2)**. The variation of Earth's orbit around the sun ranges from an almost exact circle (Eccentricity = 0.0005) to a slightly elongated shape (Eccentricity = 0.0607), it is currently at 0.016. The time frame for this cycle is approximately 100,000 years. The eccentricity influences seasonal differences, such that when the Earth is closest to the Sun, it gets more solar radiation. If this occurs during the winter, the winter is less severe.

Obliquity is the variation of the tilt of the Earth's axis away from the orbital plane **(Slide 3)**. The tilt varies 2.4 degrees, between 22.1 and 24.5 degrees, and the current tilt is 23.44 degrees and decreasing. The obliquity changes on a cycle taking approximately 41,000 years. As this tilt changes, the seasons become more exaggerated. The more tilt toward the Sun means more severe seasons, warmer summers and colder winters. The less tilt away from the Sun means cooler summers and is thought to allow for the yearly build up of snow and ice in high latitudes, possibly leading to the development of an ice sheet.

Precession is the change in the direction of the Earth's axis of rotation relative to the fixed stars, with a period of roughly 23,000 years **(Slide 4)**. This gyroscopic motion of the Earth is due to the tidal forces exerted by the Sun and the Moon on the solid Earth. When the axis is aligned so it points toward the Sun when nearest the Sun, one polar hemisphere will have a greater difference between the seasons while the other hemisphere will have milder seasons. At present, perihelion (nearest) occurs during the Southern Hemisphere's summer, and aphelion (farthest) is reached during the southern winter. In addition, the orbital ellipse itself precesses or rotates in space, primarily as a result of interactions with Jupiter and Saturn.

Using these three orbital variations, *eccentricity, obliquity and precession*, Milankovitch was able to formulate a comprehensive mathematical model that calculated latitudinal differences in exposure to the Sun's rays and the corresponding surface changes. His theory concludes that ice caps at the poles increased and decreased in size related to the exposure to the Sun's rays at high latitudes. Because the observed periodicities of climate fit so well with the orbital periods, the orbital theory has overwhelming support.

The Sun has been providing the opportunity for life on planet Earth long before the industrial revolution. Precise monitoring of solar irradiance, the amount of solar radiation reaching Earth, began in the late 1970's **(Slide 5)**. Solar irradiance varies about 1/10 of a percent over the average 10 to 12 year solar cycle. Earth absorbs 240 W of sunlight per square meter of its surface. The energy absorbed is much less than the Sun's solar irradiance of 1366 W per square meter since the circular cross-section of the Earth is only 1/4 of the Earth's surface area, and 30% of the incident light is reflected back to space. A solar forcing of 0.2 Watt is significant but not a dominant one. Albedo is a measure of how strongly an object or surface reflects light from sources such as the Sun **(Slide 6)**.

III. Climate Change after the Start of the Industrial Revolution, after 1750

A. Heating and Cooling of the Earth

Climate has two fundamental sides to it. The first, is a *natural warming* **(Slide 7)** that occurs from the Sun in the form of infrared energy. Sunlight brings energy into the climate system and most of it is absorbed by the oceans and land. Some of the heat radiates outward from the warmed Earth surface, and some is absorbed by greenhouse gases in the atmosphere that re-emit the energy in all directions. Parts of that infrared energy further warms the Earth and some is emitted back into space. The second, is an *amplified warming* **(Slide 8)** from human activity brought on by the higher concentrations of carbon dioxide (CO_2) and other "greenhouse" gases that trap more infrared energy in the atmosphere than occurs naturally. This additional heat has been warming the atmosphere **(Slide 9)**, the oceans **(Slides 10**), and raising the ocean levels through thermal expansion **(Slide 11)**. Baseline is established as 1990.

B. Climate Forcings

Earth's climate consists of the flow of heat entering and leaving the surface, and the storage of heat in the various compartments of the Earth systems; such as, the oceans, land masses, atmosphere, and snow/ice. The currently accepted global warming is 0.8°C (1.44°F), with the surface temperature minimum of -89°C (-128°F), maximum of 57.7°C (136°F), and mean of 14°C (57°F). [0.6^{0}C increase from 1900 to 2000] Only a very small amount of the heat is stored in the atmosphere. The vast majority of the heat stored at the Earth's surface is found in the ocean. The heat flux into the ocean proceeds much slower than into the atmosphere. However, given that the ocean stores so much heat, a change in the ocean is a better indicator of change in the climate than changes in air temperature.

There are various climate forcings and climate feedbacks **(Slide 12)**. These forcings are imposed externally on the climate system and can warm or cool the Earth. A feedback is an energy change within the climate system in response to a climate forcing. Examples to be discussed of these climate forcings and feedbacks are as follows:

Greenhouse Gases	*Water Vapor*	*Reflective Aerosols*	*Sun*
Ocean Acidification	*Black Carbon Aerosols*	*Aerosol Cloud Changes*	
Ozone	*Land Cover Changes*	*Volcanoes*	

The most prevalent climate forcing that warms the earth are greenhouse gases (GHG) that consist of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), ozone (O_3), and halocarbons or chlorofluorocarbons (CFC's). Carbon dioxide has both natural and human sources, but the levels are increasing primarily due to the use of fossil fuels.

Through the consistent and careful air sampling provided by David Keeling from the remote location of Mauna Loa, Hawaii the rise in CO_2 levels have been documented **(Slide 13)**. The pre-industrial level of 280 ppm was at 315 ppm when Keeling started in 1958 and has risen to 385 ppm since then. With the current rise of CO_2 levels being three times what it was when Keeling first started over fifty years ago. The annual oscillations in the graph are traced to the dominance of northern hemisphere vegetation, that draws down atmospheric carbon dioxide during the Spring and Summer growing season, and replenishes it as plant litter decays during the Autumn and Winter.

Ocean acidification is a feedback and a direct consequence of CO_2 emissions to the atmosphere, and its consequences on the global ocean are only now emerging **(Slide 14)**. The oceans have already taken up around 27% to 34% of the CO_2 produced since 1750. While this has limited the amount of CO_2 in the atmosphere, it has come at the price of a dramatic change to ocean chemistry. In particular, and of great concern, are the observed changes in ocean pH. Ocean acidification, or lowering of pH levels, is a serious threat to many organisms and may have implications for food webs and ecosystems and the multi-billion dollar services they provide.

Methane (CH_4) **(Slide 15)** levels have risen significantly since pre-industrial times due to human activities such as raising livestock, growing rice, filling landfills, and using natural gas that releases methane when the gas is extracted and transported. Methane is 22 times as effective as a GHG as CO_2.

Nitrous oxide (N_2O) **(Slide 16)** concentrations have risen primarily due to agricultural activities and land use changes. Nitrous oxide is 298 times as effective as a GHG as CO_2.

Ozone (O_3) forms naturally in the upper stratosphere, where it creates a protective shield that intercepts damaging ultraviolet radiation from the Sun. Ozone present in the upper troposphere acts as a GHG, with about 25% the effectiveness of CO_2. However, ozone produced near the Earth's surface is harmful to both animals and plants. The ozone concentrations are increasing as a result of human activities.

Halocarbons, including chlorofluorocarbons (CFC's), are chemicals that have been used for a variety of applications, such as refrigerants and fire retardants. In addition to being potent greenhouse gases, CFC's also damage the ozone layer. The production of most CFC's are now banned, so their concentrations are starting to decline, but it is a slow process.

Water vapor (H_2O) is the most potent and abundant GHG in Earth's atmosphere. However, its concentration is controlled primarily by the rate of evaporation from the oceans and transpiration from plants, rather than by human activities. Water vapor molecules only remain in the atmosphere for a few days on average. Thus, changes in water vapor are considered a climate feedback that amplifies the warming induced by other climate forcings.

Black carbon particles or "soot," produced when fossil fuels or vegetation are burned, generally have a warming effect because they absorb incoming solar radiation. Black carbon particles settling on snow or ice are a particularly potent warmer.

Aerosols and airborne particles or droplets, such as sulfate (SO_4) are a climate forcing that cool the Earth by reflecting sunlight back into space. Some aerosols also cool the Earth indirectly by increasing the amount of sunlight reflected by clouds. Human activities, such as industrial processes, produce many different kinds of aerosols. The total cooling that these aerosols produce is an uncertainty in our current understanding of present and future climate change.

Low clouds tend to cool, by reflecting more energy than they tend to trap. High clouds tend to warm, by trapping more energy than they reflect. If increased ocean evaporation leads to the formation of more low clouds that reflect more sunlight back into space, a slight cooling would result in a negative feedback cycle. On the other hand, if increased ocean evaporation leads to the formation of more high clouds, that tend to warm, the result would be a positive feedback cycle. This is another uncertainty in our current understanding of present and future climate change.

Deforestation and other changes in land use modifies the amount of sunlight reflected back to space from Earth's surface. This can lead to both positive and negative climate forcings, the net effect globally is a slight cooling or negative climate forcing.

Volcanic eruptions emit many gases. One of these is sulfur dioxide (SO_2) that once in the atmosphere forms into a sulfate (SO_4) aerosol. Large volcanic eruptions can cool the Earth slightly for several years, until the sulfate particles settle out of the atmosphere, a negative climate forcing.

C. Tipping Elements

The term ''tipping point'' commonly refers to a critical threshold beyond which a tiny change in a physical system can qualitatively alter the state or development of the system **(Slide 17)**. The term ''tipping element'' is used to describe large-scale components of the Earth system that may pass a tipping point.

1. Arctic Sea-Ice

Potential for higher average global temperatures and changes to ecosystems

As sea-ice melts, it exposes a much darker ocean surface that absorbs more radiation and amplifies the warming. Positive ice-albedo feedback dominates external forcing in causing the thinning and shrinkage of the arctic sea ice, leading some to suggest that this system may already have passed a tipping point, although others disagree. Given that the observed rate of arctic sea-ice decline is greater than what has been modeled, a summer ice-loss threshold, if not already passed, may be very close and a transition could occur well within this century.

2. Greenland Ice Sheet (GIS)

Potential for global sea level rise of up to 7 meters

Recent observations show the surface mass balance is declining and contributing to net mass loss from the GIS that are accelerating. These changes include melting and thinning of the coastal margins and surging of outlet glaciers, that may be contributed to by the intrusion of warming ocean waters. If a threshold is passed, the IPCC gives a greater than 1,000-year timescale for GIS collapse. However, given the IPCC's acknowledged lack of processes that could accelerate collapse in current models, and their inability to simulate the rapid disappearance of continental ice at the end of the last ice age, a lower limit of 300 years is conceivable.

3. **West Antarctic Ice Sheet (WAIS)**
   Potential for global sea level rise of up to 5 meters

Most of the WAIS is grounded below sea level and has the potential to collapse if grounding-line retreat triggers a strong positive feedback whereby ocean water undercuts the ice sheet and triggers further separation from the bedrock. WAIS collapse may be preceded by the disintegration of ice shelves and the acceleration of ice streams. Ice shelf collapse could be triggered by the intrusion of warming ocean water beneath them or by surface melting. Although the timescale is highly uncertain, a qualitative WAIS change could occur within this millennium, with collapse within 300 years being a worst-case scenario. Rapid sea-level rise of greater than 1 m per century is more likely to come from the WAIS than from the GIS.

4. **Atlantic Thermohaline Circulation (THC)**
   Potential for disruptions to Gulf Stream and changes to weather patterns

The Thermohaline Circulation (THC) is that part of the ocean circulation that is driven by fluxes of heat and freshwater across the sea surface and subsequent interior mixing of heat and denser salt water. The large heat transport of the thermohaline circulation throughout the ocean makes it an important climate component. Its non-linear and potentially abrupt response to forcing and the disruption of the planetary exchange of heat from the tropics to the poles has been invoked to explain past abrupt glacial climate changes.

A shutoff in North Atlantic Deep Water (NADW) formation and the associated Atlantic THC can occur if sufficient freshwater or heat or both enters the North Atlantic to halt density-driven north Atlantic deep water formation. Under sufficient north Atlantic freshwater forcing, all models exhibit a collapse of convection. In some experiments, this collapse is reversible after the forcing is removed, in others it is irreversible.

5. **El Niño–Southern Oscillation (ENSO)**
   Potential for changes to weather patterns, including increased droughts, especially in Southeast Asia

The El Niño–Southern Oscillation (ENSO) phenomenon, originating in the tropical pacific, is the strongest natural inter-annual climate signal and has widespread effects on the global climate system and the ecology of the tropical pacific. Any strong change in ENSO statistics will therefore have serious climatic and ecological consequences. Increased ocean heat uptake could cause a permanent deepening of the thermocline in the east equatorial pacific and a consequent shift from present day ENSO variability to greater amplitude or more frequent El Niños or both. The required warming can be accessed this century with the transition happening within a millennium, but the existence and location of any threshold is particularly uncertain.

6. **Indian Summer Monsoon (ISM)**
Potential for widespread drought and changes to weather patterns

The land-to-ocean pressure gradient, that drives the monsoon circulation, is reinforced by the moisture the monsoon itself carries from the adjacent Indian Ocean. Consequently, any changes in the state of equilibrium that tends to weaken the driving pressure gradient has the potential to destabilize the monsoon circulation.

7. **Sahara/Sahel and West African Monsoon (WAM)**
Potential for changes to weather patterns, including potential greening of the Sahara and Sahel; one of the few positive tipping elements

Greenhouse gas forcing is expected to increase the Earth's sea surface temperature gradient and thereby increase Sahel rainfall, the resulting moisture will wet the Sahel and support greening of the Sahara. Increasing atmospheric CO_2 has been predicted to cause future expansion of grasslands into up to 45% of the Sahara, at a rate of up to 10% of Saharan area per decade. Such greening of the Sahara/Sahel is a rare example of a beneficial potential tipping element.

8. **Amazon Rainforest**
Potential for massive extinctions and decreased rainfall

A large fraction of precipitation in the Amazon basin is recycled, and therefore simulations of Amazon deforestation typically generate approximately 20% to 30% reductions in precipitation, lengthening of the dry season, and increases in summer temperatures that would make it difficult for the forest to reestablish. Dieback of the Amazon rainforest has been predicted to occur at about 3°C to 4°C global warming because of a more persistent El Niño state that leads to drying over much of the Amazon basin. Changes in fire frequency will be amplified by forest fragmentation due to human activity. Land-use changes alone could potentially bring forest cover to a critical threshold. The fate of the Amazon Rainforest may be determined by a complex interplay between direct land-use change, the response of regional precipitation, and El Niño–Southern Oscillation to global forcing.

9. **Boreal Forest**
Potential for severe changes to boreal forest ecosystems

The Boreal Forest system exhibits a complex interplay between tree physiology, permafrost, and fire. Due to climate change, increased water stress, increased peak summer heat stress causing increased mortality, vulnerability to disease and subsequent fire, as well as decreased reproduction rates could lead to large-scale dieback of the current boreal forests, with transitions to open woodlands or grasslands. Studies suggest a threshold for boreal forest dieback of approximately 3°C global warming, but limitations in existing models and physiological understanding make this highly uncertain.

IV. Summary

Past societies have reacted when they understood that their own activities were causing unexpected harmful environmental change by controlling or modifying the offending activities. The scientific evidence has now become overwhelming that human activities, especially the combustion of fossil fuels, are influencing the climate in ways that threaten the well-being and continued development of human society. If humanity is to learn from history and to limit these threats, the time has come for stronger control of the human activities that are changing the fundamental conditions for life on Earth.

To decide on effective control measures, an understanding of how human activities are changing the climate, and of the implications of unchecked climate change, needs to be widespread among world and national leaders, as well as in the public. This understanding is communicated through six key messages as established by the International Alliance of Research Universities - Synthesis Report for the international scientific congress entitled Climate Change: Global Risks, Challenges and Decisions held in Copenhagen from March 10-12, 2009.

Key Messages:

1. Climatic Trends

Recent observations show that greenhouse gas emissions and many aspects of the climate are changing near the upper boundary of the IPCC range of projections. Many key climate indicators are already moving beyond the patterns of natural variability within which contemporary societies and economies have developed and thrived. These indicators include global mean surface temperature, sea-level rise, global ocean temperature, arctic sea ice extent, ocean acidification, and extreme climatic events. With unabated emissions, many trends in climate will likely accelerate, leading to an increasing risk of abrupt or irreversible climatic shifts.

2. Social and Environmental Disruption

The research community provides much information to support discussions on “dangerous climate change”. Recent observations show that societies and ecosystems are highly vulnerable to even modest levels of climate change, with poor nations and communities, ecosystem services and biodiversity particularly at risk. Temperature rises above 2^{o}C will be difficult for contemporary societies to cope with, and are likely to cause major societal and environmental disruptions through the rest of the century and beyond.

3. Long-term Strategy: Global Targets and Timetables

Rapid, sustained, and effective mitigation based on coordinated global and regional action is required to avoid “dangerous climate change” regardless of how it is defined. Weaker targets for 2020 increase the risk of serious impacts, including the crossing of tipping points, and make the task of meeting 2050 targets more difficult and costly. Setting a credible long-term price for carbon and the adoption of policies that promote energy efficiency and low-carbon technologies are central to effective mitigation.

4. Equity Dimensions

Climate change is having, and will have, strongly differential effects on people within and between countries and regions, on this generation and future generations, and on human societies and the natural world. An effective, well-funded adaptation safety net is required for those people least capable of coping with climate change impacts, and equitable mitigation strategies are needed to protect the poor and most vulnerable. Tackling climate change should be seen as integral to the broader goals of enhancing socioeconomic development and equity throughout the world.

5. Inaction is Inexcusable

Society already has many tools and approaches – Economic, Technological, Behavioral, and Managerial – to deal effectively with the climate change challenge. If these tools are not vigorously and widely implemented, adaptation to the unavoidable climate change and the societal transformation required to decarbonize economies will not be achieved. A wide range of benefits will flow from a concerted effort to achieve effective and rapid adaptation and mitigation. These include job growth in the sustainable energy sector; reductions in the health, social, economic and environmental costs of climate change; and the repair of ecosystems and revitalization of ecosystem services.

6. Meeting the Challenge

If the societal transformation required to meet the climate change challenge is to be achieved, then a number of significant constraints must be overcome and critical opportunities seized. These include reducing inertia in social and economic systems; building on a growing public desire for governments to act on climate change; reducing activities that increase greenhouse gas emissions and reduce resilience (such as, subsidies); and enabling the shifts from ineffective governance and weak institutions to innovative leadership in government, the private sector and civil society. Linking climate change with broader sustainable consumption and production concerns, human rights issues and democratic values is crucial for shifting societies towards more sustainable development pathways.

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