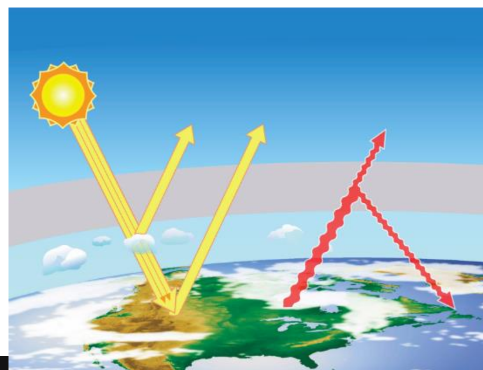
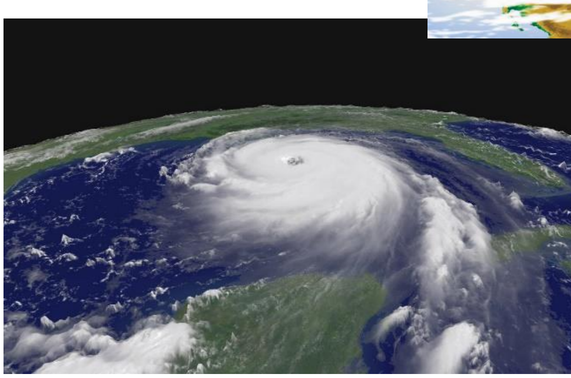
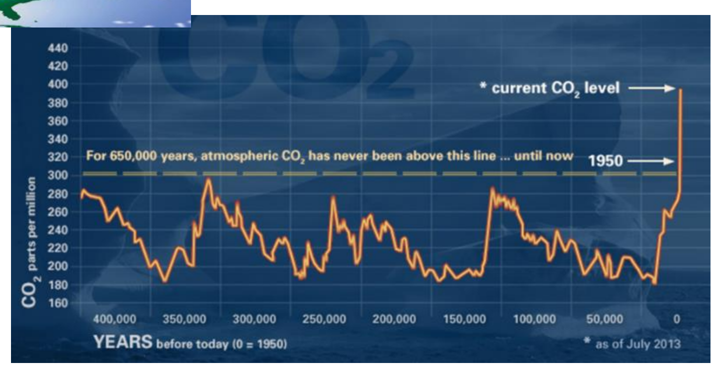
Internal Medicine Ground Rounds
November 15, 2019

The Scientific Evidence on Climate Change

And the Ethics of Skepticism vs Denialism







Robert W. Haley, M.D.
Division of Epidemiology
Department of Internal Medicine
University of Texas Southwestern Medical Center
Dallas, Texas

This is to acknowledge that Robert W. Haley, MD has disclosed that he does not have any financial interests or other relationships with commercial concerns related directly or indirectly to the program. Dr. Haley will not be discussing off-label uses in his presentation.

Biographical Information:

Robert W. Haley, M.D., is Professor of Internal Medicine, Distinguished Teaching Professor, and holder of the U.S. Armed Forces Veterans Distinguished Chair in Medical Research Honoring America's Gulf War Veterans endowed by Ross Perot and the Perot Foundation. After serving 10 years at the U.S. Centers for Disease Control and Prevention (CDC), he joined the UT Southwestern faculty, founding the Division of Epidemiology which he heads. In addition to attending on Parkland Medicine and teaching a course in epidemiology for the clinical investigator and SAS computing for research fellows and young faculty, his research currently focuses on the neurological and genetic basis for sarin-related Gulf War illness and the possible role of paraoxonase in congestive heart failure, and he leads clean air policy development in the Dallas County Medical Society and the Texas Medical Association. While conducting an epidemiologic investigation of Dallas' 2012 West Nile virus epidemic, he became interested in the problem of climate change which is playing an increasingly important role in the risks of infectious diseases. Realizing that the scientific evidence on climate change is not well known in the medical profession, he began lecturing on the subject first to medical groups and then to lay audiences.

Purpose and Overview:

The purpose is to introduce the main empirical evidence behind the scientific consensus that human-caused carbon emissions are warming the planet and threatening the health and survival of the world population. Following a "case report" of the role of climate change in causing the 2012 epidemic of West Nile encephalitis in Dallas, the presentation will summarize the evidence that addresses the 4 fundamental questions of the problem: Is the earth's surface warming? Is the warming due to human effects or natural phenomena? Is the warming climate a serious threat to humans? Should society invest in curtailing climate change? The first two are purely empirical questions which have been thoroughly answered. The last two involve value judgments and economic consequences which have provoked denial of the first two, stymying planet-saving action. Finally the presentation will explain the distinction in scientific ethics between *skepticism* and *denialism* and some reasons that people confuse them. The conclusion will consider the moral imperative that physicians protect our patients and the rest of humanity by working toward a solution to climate change, just as the profession did 5 decades ago in leading opposition to world destruction by nuclear warfare.

Educational Objectives:

1. Explore the main evidence proving that the surface temperature of the earth has been warming since the beginning of the Industrial Era.
2. Review the main evidence establishing that human-related carbon emissions are the primary cause of global warming and climate change.
3. Consider the main scientific evidence showing important ways climate change is threatening the health and survival of humans.
4. Consider what measures our country must take to curtail and reverse climate change.
5. Understand the distinction between scientific skepticism and denialism and the moral imperative for physicians to protect our patients and the rest of humanity by working toward a solution to climate change, just as the profession did 5 decades ago in leading opposition to world destruction by nuclear warfare

"Case Report"

In 1999 West Nile encephalitis was imported into New York. It reached Dallas in 2002. For the next 10 years we had few cases, with a first small epidemic in 2006 (Fig. 1). In 2012 we had the largest epidemic in the country, with 173 encephalitis cases on ventilators in ICUs and 21 deaths. Since then we've had rare cases each year as before.[1] The main predictors of the number of cases were fewer number of hard freeze days and unusually warm springs (Fig. 2).

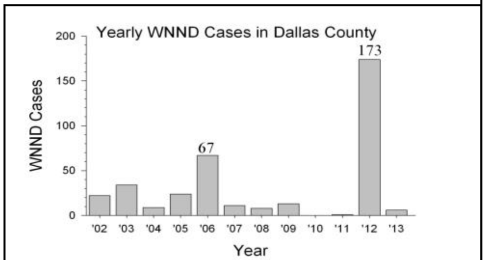


Fig. 1. Cases of West Nile neuroinvasive disease in Dallas County by year, 2002-2013.

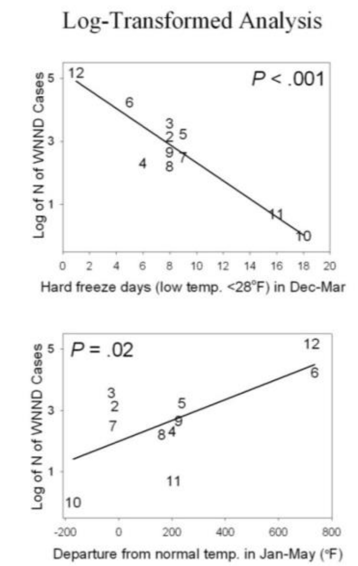


Fig. 2. Association of the yearly number of cases of WNND with lower number of hard freeze days and unusually warm springs.

These findings raised the question of whether this highly unusual epidemic might have been caused by global warming. In fact, our winters and springs have been getting warmer, and 2006 and 2012 were the warmest on record. Fewer hard freeze days increase over-wintering of infected mosquitoes and allow early virus introduction in the spring. Warmer spring temperatures speed viral replication and increase mosquito biting activity. So do we need to curtail global warming to prevent this from becoming more frequent? This brings us face to face with the question, "Do we believe in climate change?" and "If so, why?" To answer this we need to know the evidence the theory is base on.

To understand the scientific basis for climate change, it is important to realize that the issue really involves 4 separate questions, and failure to distinguish them is a major cause of confusion. The 4 questions are:

1. Is the earth's surface warming?
2. Is the warming due to human effects or natural phenomena?
3. Is the warming climate a serious threat to humans?
4. Should society invest in curtailing climate warming?

The first 2 questions are purely empirical ones with definite answers strongly supported by evidence. The last 2 involve value judgments and economic consequences that spark debate. Unfortunately, the debate over the last 2 has been unfairly generalized to the first 2, stymying action.

Q1. Is the earth's surface temperature warming?

Ten published studies have reconstructed longitudional surface temperatures back 1-2 thousand years by analyzing surrogates of temperature such as pollen counts in ice core samples from glaciers and ice sheets, tree rings, corals, lake or ocean sediments and historical data. One thousand-year reconstructions from 10 published sources agree that a slow decreasing trend in global temperature ended abruptly with the beginning of the Industrial Age in the late Nineteenth Century, followed by a steep climb in temperatures (Fig. 3a). These trends have been extended back to a 2000-year record (Fig. 3c).[2] The increasing trend has continued to the present, with a leveling off in the 1940s due to industrial slowdown from World War II, followed by a steep climb beginning around 1980 and continuing to the present (Fig. 3b).[3] As of this year the global surface temperature has warmed a full 1ºC (1.9ºF) since the pre-industrial age.[4]

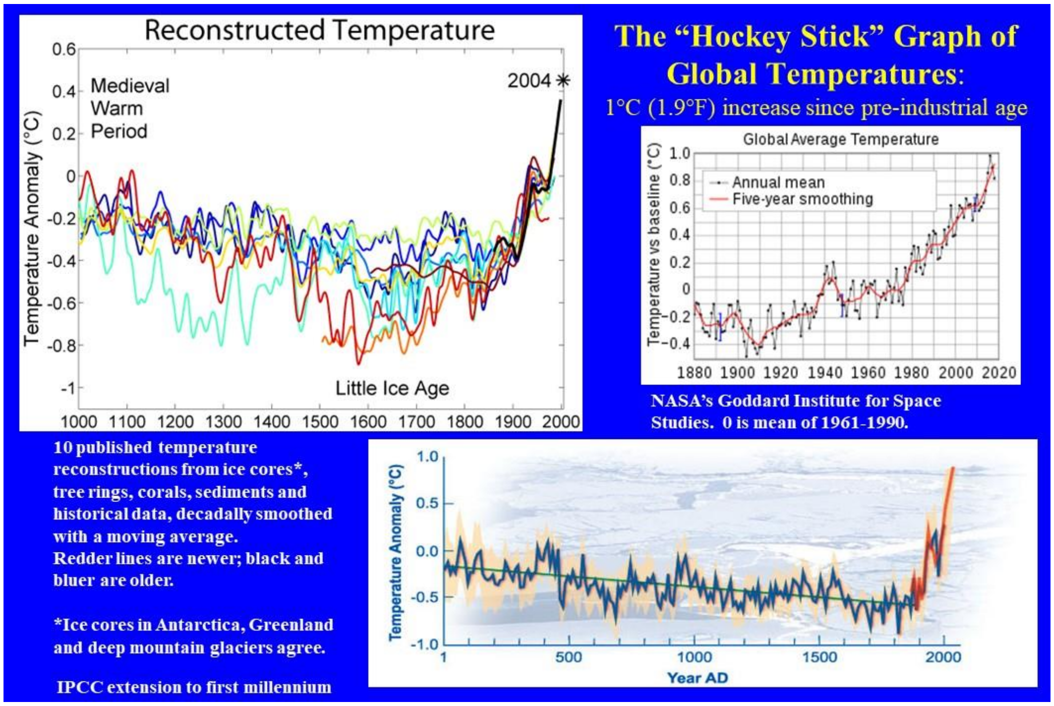


Fig. 3. Longitudinal trends in global temperature.

This finding of a rapid rise in global surface temperature since the pre-industrial age is further verified by well characterized trends in other indicators that should be affected by the progressively increasing trend (Fig. 4).

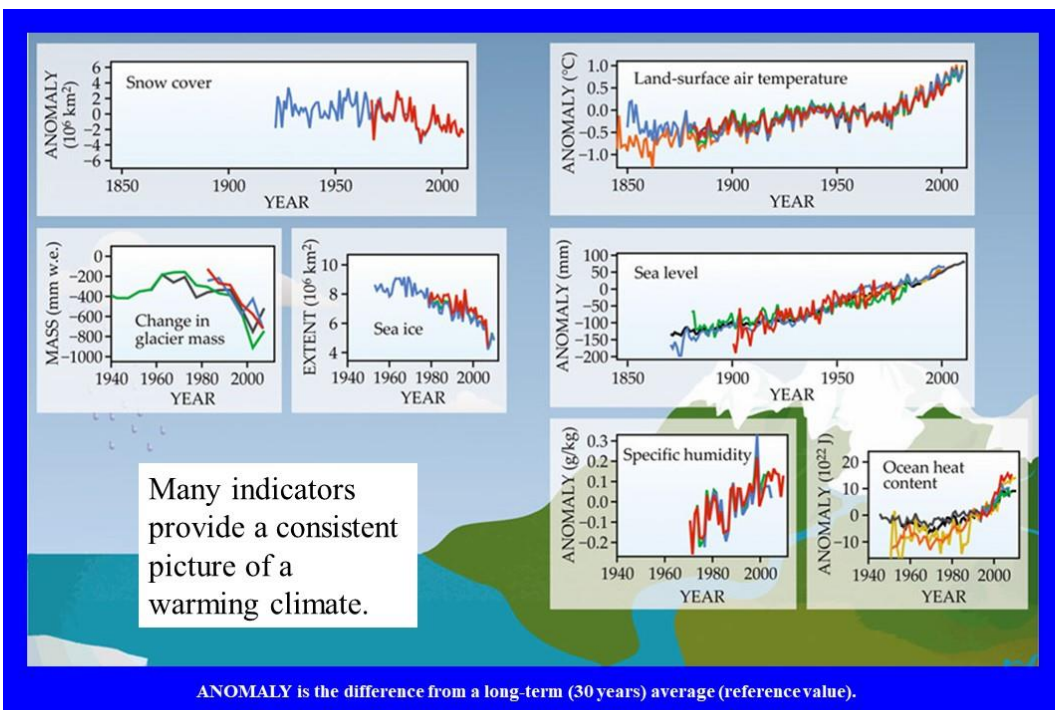


Fig. 4. Longitudinal trends in other indicators that should be affected by rising global temperatures.

An important feature of global warming is that the degree of warming is geographically highly variable. This is a major determinant of the great geographical differences in the effects on climate. For example, land areas are warming faster than oceans; the Northern Hemisphere is warming faster than the Southern Hemisphere, and the Arctic region is warming the fastest of all (Fig. 5). Whereas the average global temperature has increased 1ºC since the pre-industrial age, the average temperature of the Arctic region has warmed more than 3ºC, and the adverse effects on the region are likewise disproportionately worse.

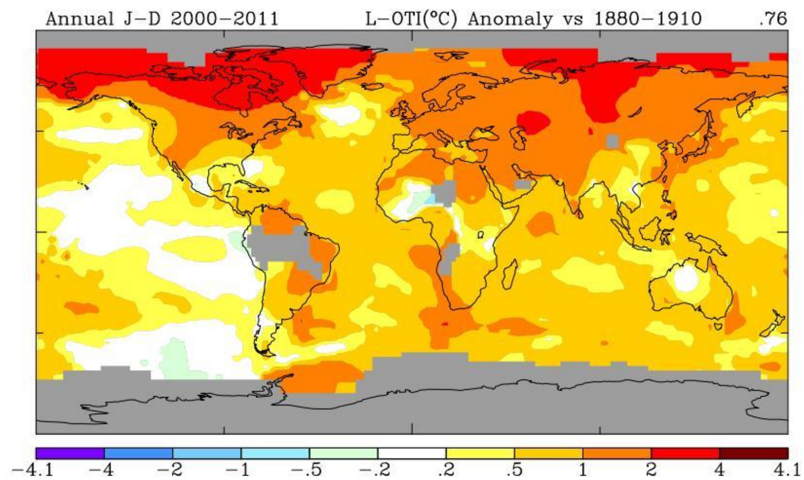


Fig. 5. Regional differences in the degree of atmospheric warming.

The conclusion for question 1 "Is the Earth's surface temperature increasing?" is clearly yes.

Q2. Is the warming due to human influences or natural phenomena?

Prediction of the Greenhouse Effect

The idea that the buildup of certain gases in the atmosphere would warm the atmosphere at the earth's surface, known as the "greenhouse effect," was first described by Joseph Fourier in 1824. In 1859 John Tyndall measured the radiative properties of many gases. In 1896, Svante Arrhenius quantified the effect as what is known as the Greenhouse Law:

$$\Delta F = \boldsymbol{\alpha} \ln(C/C_0)$$

A simple matter of physics, the atmospheric temperature (*F*) will increase as a linear function **α** of a logarithmic increase in atmospheric CO_2 concentration C/C_0. As a consequence of this equation, Arrhenius predicted that industrial CO_2 emissions were sufficient to affect the average global temperature, and a doubling of the current atmospheric CO_2 (280 ppm) would increase average global temperature by 5ºC (9ºF). However, in 1896 he felt that industry could never emit enough CO_2 to make a detectable difference in temperatures. Arrhenius received the Nobel Prize in chemistry in 1903, the first Swedish scientist to receive the honor.

How the Greenhouse Effect works

The sun's light heats the earth (Fig. 6). Its light is partially reflected back into space by clouds, air pollution, and light land surfaces such as ice, while the rest is absorbed by the surface, thus generating heat. At night some of the heat absorbed during the day is radiated back into space as infrared radiation, thus cooling the earth overnight. Greenhouse gases, such as CO_2, methane (NH_4), nitrogen gases (N_2O), ozone (O_3), chlorofluorocarbons (CFCs) and water vapor (H_2O), trap some of the outgoing infrared radiation and reflect it back to earth, thus acting as a blanket keeping the earth warmer.

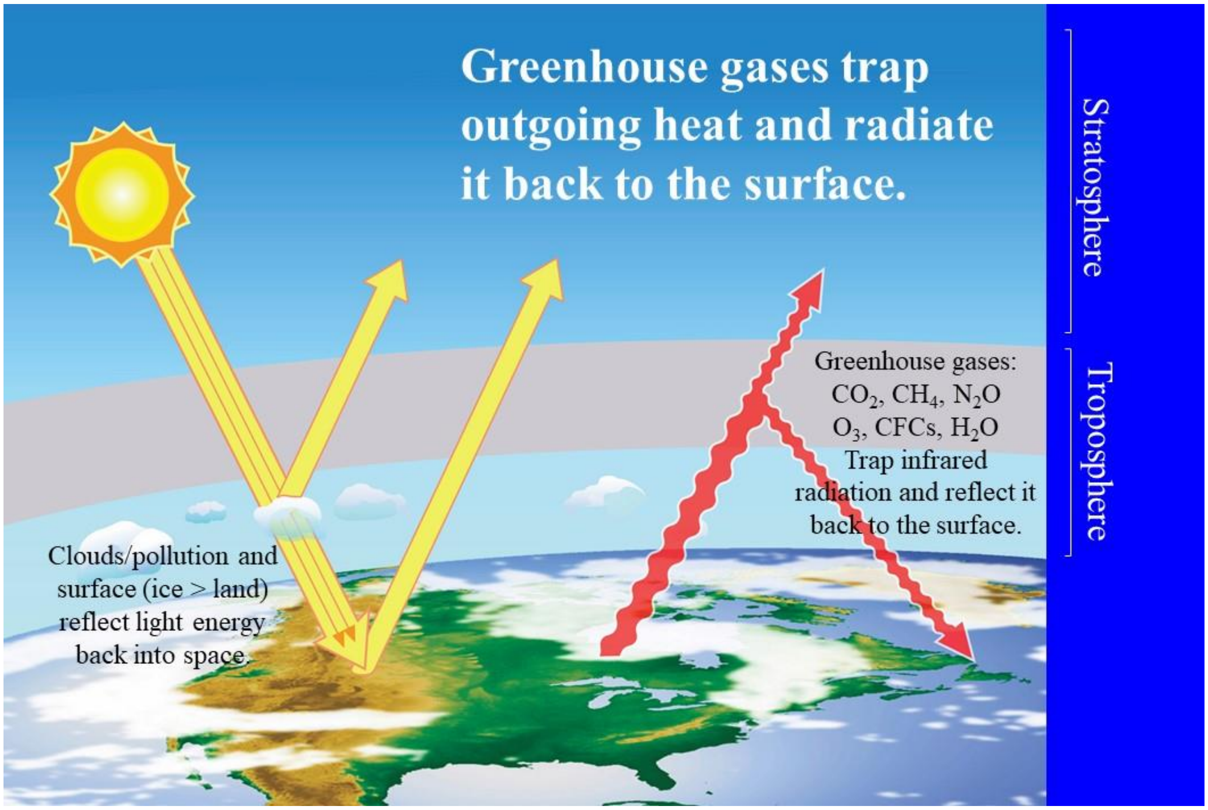


Fig. 6. The Greenhouse Effect.

Atmospheric CO_2 concentrations and carbon emissions

CO_2 emissions. CO_2 is a potent greenhouse gas, which, once emitted, remains in the atmosphere for hundreds or thousands of years. The average annual CO_2 concentraton in the atmosphere has been estimated from ice core sampling up to 1960; thereafter, it has been measured directly in an atmospheric station at the top of Mt. Mauna Loa in Hawaii, where it is exposed only to the winds from the vast Pacific Ocean to its west, which accurately measure the average global CO_2 concentration of air (Fig. 7a). The annual level of carbon emissions from human activity since 1850 follow exactly the annual level of the average global temperature (Fig. 7a,c). The same tracking is apparent in comparing annual levels over the past 1,000 years (Fig. 7d).

Altogether since the pre-industrial age, man has emitted an estimated 400 gigatons (Gt) of carbon into the atmosphere (a Gt is 1 billion tons). Presently roughly 160 Gt are in the atmosphere, and 120 Gt are dissolved in the oceans. It is unclear where the remaining 200 Gt is stored; it is called the "missing sink."

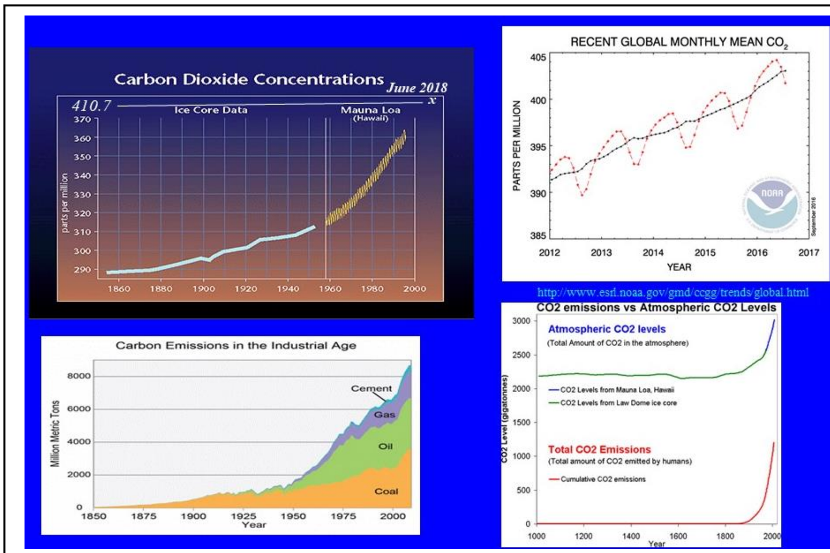


Fig. 7. Longitudinal trends in atmospheric CO_2 levels and CO_2 emissions.

The additional carbon has increased the atmospheric CO_2 level to 410 ppm as of November 2019. In the pre-industrial age, the CO_2 level averaged 280 ppm, and over the prior 650,000 years, it had never exceeded 300 ppm.

Methane (CH_4) emissions. Methane is natural gas. Human-caused emissions are mainly from leaking natural gas wells and pipelines. Natural emissions are mainly from anaerobic decomposition of plant matter, rice production, livestock belching, and forect fires. CH_4 is a greenhouse gas which, once emitted, remains in the atmosphere only 10-20 years. Although its atmospheric concentration is far lower than that of CO_2, it is important because its global warming potential (GWP) is far greater than that of CO_2. The GWP100, measured over 100 years, is 28-36 times that of CO_2; wherease, its GWP20, over 20 years from emission, is 86 times that of CO_2. So methane emissions are of greater importance when the concern is for the near-term effects of global warming on climate.

Paleoclamatic fluctuations of the atmospheric CO_2 concentration. Atmospheric CO_2 levels have been measured by ice core sampling, etc., over at least the past 800,000 years (Fig. 8). The longitudinal plot shows a dramatic cyclical fluctuation between 180 ppm and 300 ppm, which has been recurring for the past 34 million years. At its low points the earth plunges into an ice age (called a "Glacial" period); while at its high points, the earth experiences temperate climate (called an "Inter-glacial" period). The fluctuations occur irregularly at intervals of between 75,000 and 125,000 years. **The main point is that the atmospheric CO_2 level has not exceeded 300 ppm for at least the last 650,000 years (almost certainy many times further back than that), and the dramatic rise since the pre-industrial age to the present level of 415 ppm has not happened for millions of years.**

Notice particularly the abrupt rise that ends each ice age and brings in the temperate period. Somehow massive stores of carbon are mobilized and released into the atmosphere in a relatively short time. A recent study indicated that this happens when small changes in earth's orbit (possibly from the earth's wobble) cause melting of the Arctic ice cap, dumping fresh water into the northern Atlantic, blocking the Atlantic circulation, heating the Antarctic, and causing CO_2 to bubble up from the southern oceans, causing a runaway greenhouse effect (more about this below). Thus, having artificially pushed the CO_2 level far above what it has been, we have entered uncharted waters where it is impossible to predict what might result. We know there are still massive stores of carbon sequestered away which once were in the atmosphere, but we do not know if the present rise could trigger a massive release.

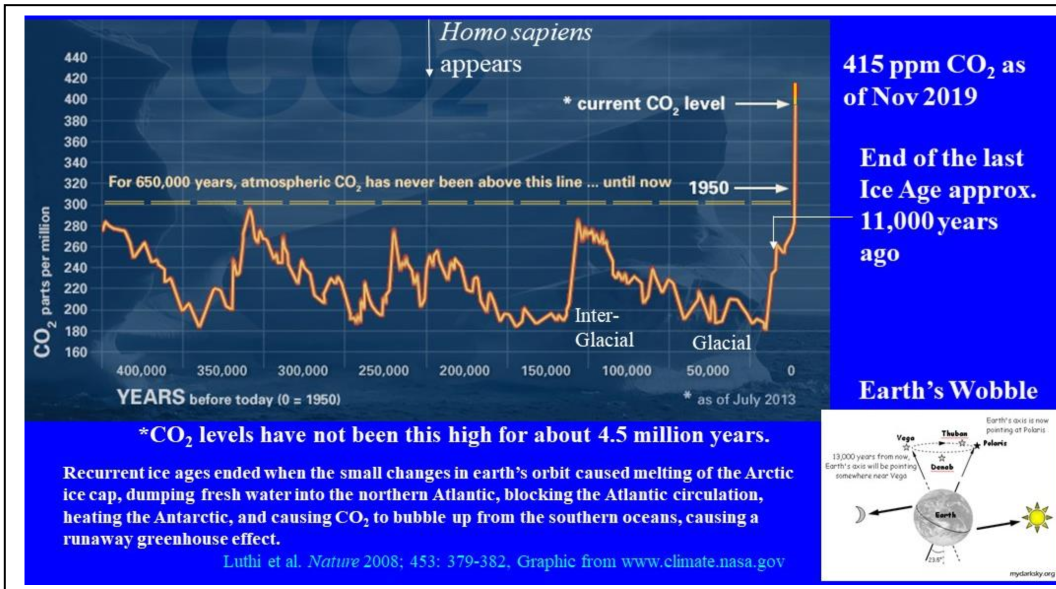


Fig. 8. Paleoclimatic fluctuation of the atmospheric CO_2 level from ice core sampling, etc., emphasizing the singularity of today's level.

Could the recent rise in CO_2 levels be caused by an increase in the sun's energy output?
One theory of CO_2 rise is that the sun has recently gotten hotter thus heating up the earth's atmosphere. Two sets of measurements have ruled out this possibility.

First, measurements back to the pre-industrial era show that since the 1950s, the total solar irradiance has remained approximately stable while the earth's atmospheric CO_2 level has relentlessly climbed (Fig. 9).

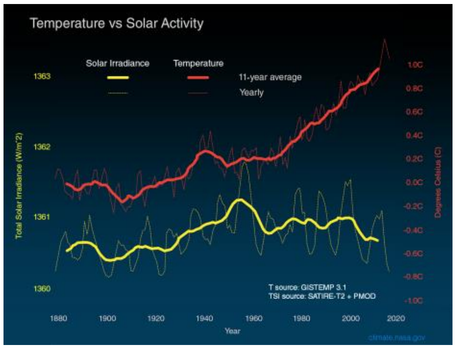


Fig. 9. Since 1960 solar irradiance (yellow line) has remained stable while global temperature (red line) has steadily climbed.

Second, satellite measurements have demonstrated that, as the average global temperature of the earth's surface (the troposphere) has been warming, the temperature of the stratosphere, above the concentration of greehhouse gases, has been cooling (Fig. 10). Solar heating would progressively warm the stratosphere as well as the troposhpere.

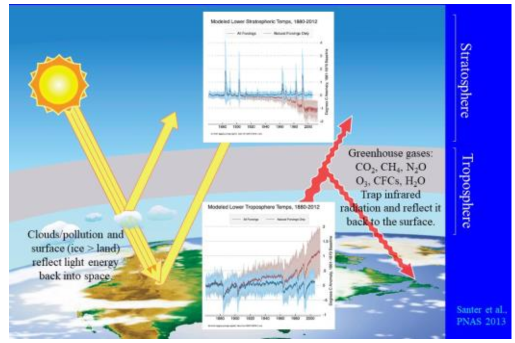


Fig. 10. Global temperatures of the troposphere and the stratosphere since 1880. The blue lines (error bars) are from super computer models excluding anthropogenic forcings, and the red lines (error bars) are the observed values.

Direct evidence of the Greenhouse Effect

Decisive evidence of the Greenhouse Effect has come from measurement of the energy being reflected back to eath at night and from that escaping into space (Fig. 11).

First, measurement and spectral analysis of infrared energy at the earth's surface at night has shown that the energy reflected back to the earth's surface at night is almost entirely confined to the wave lengths that are absorbed and reflected back by the greenhouse gases: CO_2, CH_4, O_3, N_2O and CFCs[5,6] (Fig. 11a).

Second, a long-term satellite study found that from 1970 to 1996 the amount of energy escaping into space declined only for the wave lengths absorbed by the greenhouse gases[7] (Fig. 11b).

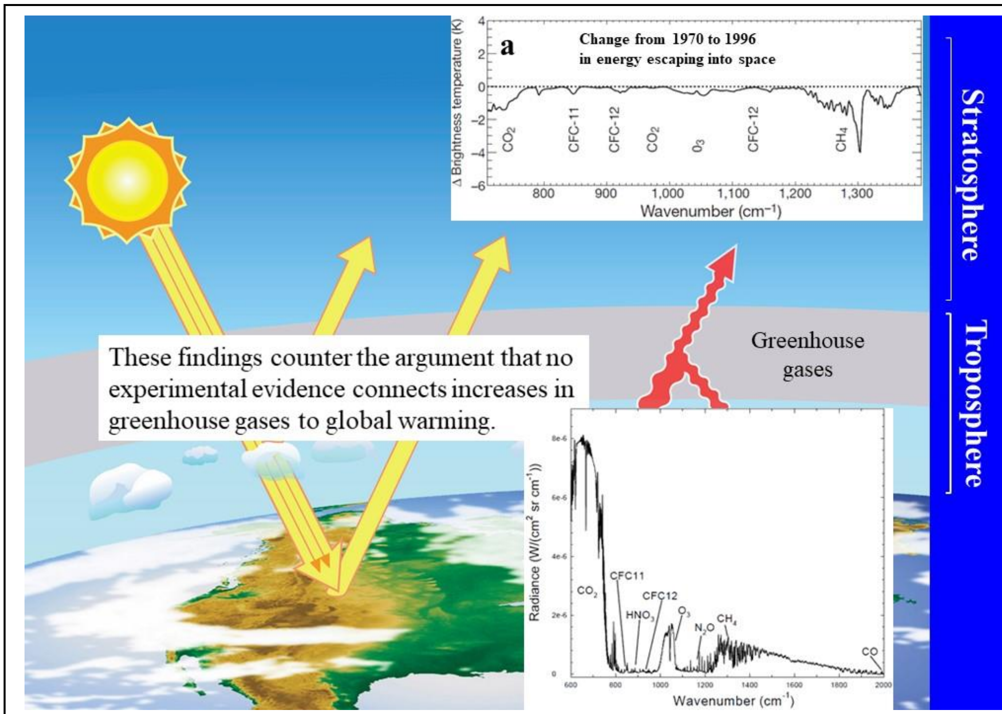


Fig. 11. Wavelengths of infrared energy reflected back to earth's surface at night and blocked from escaping into space

Evidence that the added CO_2 is from burning of fossil fuels: 1. O_2 decline

There is a finite number of possible sources for the additional CO_2 that has warmed the planet over the past 100 years. The major ones are volcanos, putrefacton of organic material, and anthropogenic burning of fossil fuels: coal, oil and natural gas. While the volcanos and purefaction generate CO_2 anaerobically, only fossil fuel burning does so by oxidation. Burning involves combining oxygen with carbon to produce CO_2 and heat by:

Heat

$$C + 2O = CO_2$$

Consequently, as burning fossil fuels adds 1 molecule of CO_2 to the atmosphere, 2 atoms of oxygen must disappear. Long-term measurements of atmospheric gas composition have demonstrated that, at least since 1990 (the era of the geometric increase in global temperature), the concentration of oxygen has been declining at exactly twice the rate that CO_2 has been increasing[8,9] (Fig. 12). This excludes natural sources of CO_2 and by elimination confirms the role of fossil fuel burning.

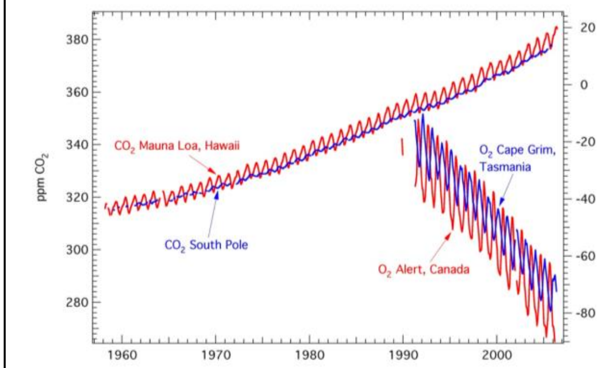


Fig. 12. The oxygen concentration of the atmosphere has been declining at exactly twice the rate that CO2 has been increasing, supporting causation by fossil fuel burning.

Evidence that the added CO_2 is from burning of fossil fuels: 2. Atomic fingerprint

Two isotopes of carbon predominate in the atmosphere: carbon 12 (^{12}C) and carbon 13 (^{13}C). Carbon 12 has 6 neutrons, and carbon 13 has 3 (Fig. 13 top).

Carbon in fossil fuels, which were formed by a primitive photosynthesis process millions of years in the past, has a lower $^{13}C/^{12}C$ ratio than that in the natural atmosphere. Consequently, if the CO_2 that has recently been added to the atmosphere is from fossil fuel burning, the atmospheric $^{13}C/^{12}C$ ratio should have fallen since the pre-industrial era.

Ice core sampling demonstrates that the $^{13}C/^{12}C$ ratio was stable for >1,000 years until the start of the industrial age when it began falling in direct proportion to the increase in the atmospheric CO_2 level[10] (Fig. 13 bottom). Moreover the rate of change in the $^{13}C/^{12}C$ ratio is strongly correlated with the rate of increase in anthropogenic CO_2 emissions[11] (Fig. 13 inset).

Thus the change in the atomic fingerprint of the atmosphere further supports an anthropogenic source of the recent atmospheric CO_2 rise.

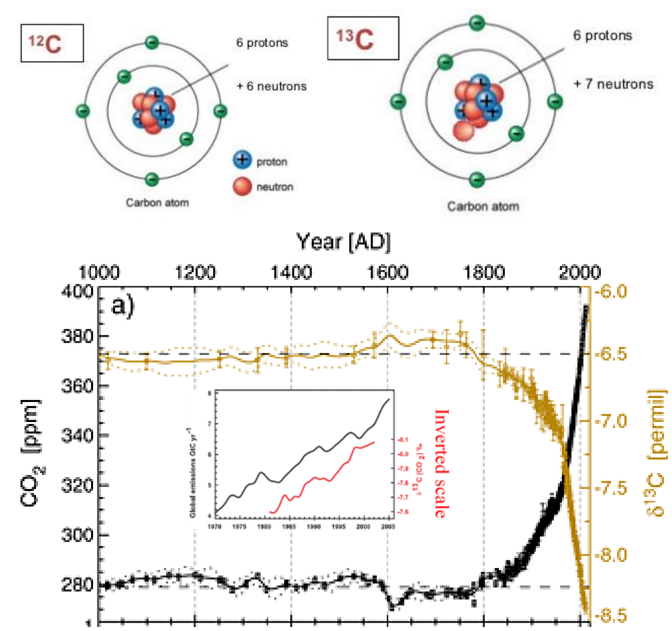


Fig. 13. Since the beginning of the post-industrial age, the atmospheric $^{13}C/^{12}C$ ratio has been falling as the CO_2 concentration has been rising, and the 2 trends are highly correlated (inset). $\delta^{13}C$ = change in the $^{13}C/^{12}C$ ratio.

The conclusion for question 2 "Is the warming due to human influences or natural phenomena?" is the latter: it is from human (anthropgenic) influences, primarily fossil fuel burning.

Q3. Is the warming climate a threat to humans?

The average global temperature has now increased by 1ºC (1.9ºC) since the pre-industrial era (Fig. 14). Already we are seeing dramatic effects from this small change. The most recent IPCC report urges keeping the warming below 1.5ºC to avoid severe damage, finding that reaching 2ºC warming would be catastrophic to:

- Food production
- Water supplies
- Human health
- Coastal cities
- Energy production
- National security
- Continued economic prosperity

Current patterns of anthropogenic release of CO_2 and methane, if not curtailed, will reach the point of irreversability between 2036 and 2046, if not sooner, and 3ºC warming by 2,100.

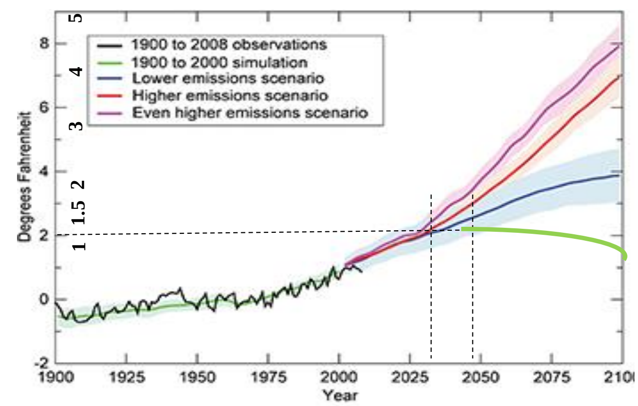


Fig. 14. Four scenarios for the degree of climate warming by 2,100. The true course depends on 2 uncertainties: the degree of climate sensitivity and the extent of human action to curtail it.

The effects of climate change

The major effects that climate change have been widely discussed[4] and will only be listed here to allow more discussion of the lesser known mechanisms underlying the changes.

- Extreme heat waves for longer
  - Threats to health, energy, agriculture, etc.
- Changes in precipitation patterns
  - More droughts in the Southwest reducing crop yields
  - More wildfires
- Longer frost-free season/fewer freezes
  - Longer growing season
  - Increasing disease vectors and earlier epidemic conditions
  - Increasing tree diseases, die-offs and deforestations
- Ocean acidification
  - Fish species migrate out of traditional fisheries.
  - Species that cannot adapt to rapid change decline.
  - Species extinctions constrain food supply
- Disappearing glaciers
  - Threaten water supplies to major cities
- More rainfall in the Midwest
  - Death and property losses from flooding
  - Water quality loss and increased water-borne diseases
- Stronger storms
  - Tornadoes and hurricanes of higher grades, more hail storms
- Sea level rise
  - Higher storm surges
  - Eventual loss of coastal cities

Disease-causing effects of climate change
https://www.cdc.gov/climateandhealth/effects/default.htm

- Increased numbers and efficiency of vector transmission (e.g., West Nile)
- Expanded range of vector-borne diseases (e.g., dengue, Chagas, leishmaniasis)
- More rapid emergence of novel infectious diseases (e.g., "bird flu")[12]
- Increased asthma and COPD exacerbations and heart attacks from air pollutants (e.g., ozone, particulates)
- Increased allergies and asthma from higher pollen production and longer allergy season
- Greater risk of food-borne and water-borne diseases (e.g., cholera)
- More extreme heat waves and heat-related illness (e.g., heat stroke, deaths)
- Increased severity of extreme weather events (e.g., hail, tornados, hurricanes)
- Famines from drought, glacial shrinkage and reduced aquatic abundance

Examples of infectious diseases already affected[13]

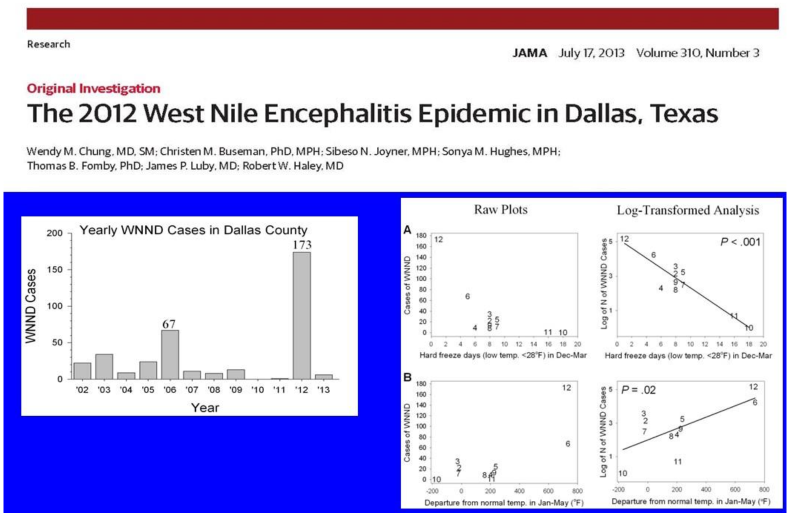
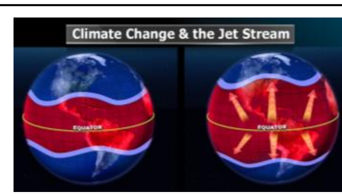


Fig. 15. The effect of higher temperatures with fewer hard freezes in winter and an earlier, warmer spring were apparent in the 2012 Dallas epidemic of West Nile encephalitis.



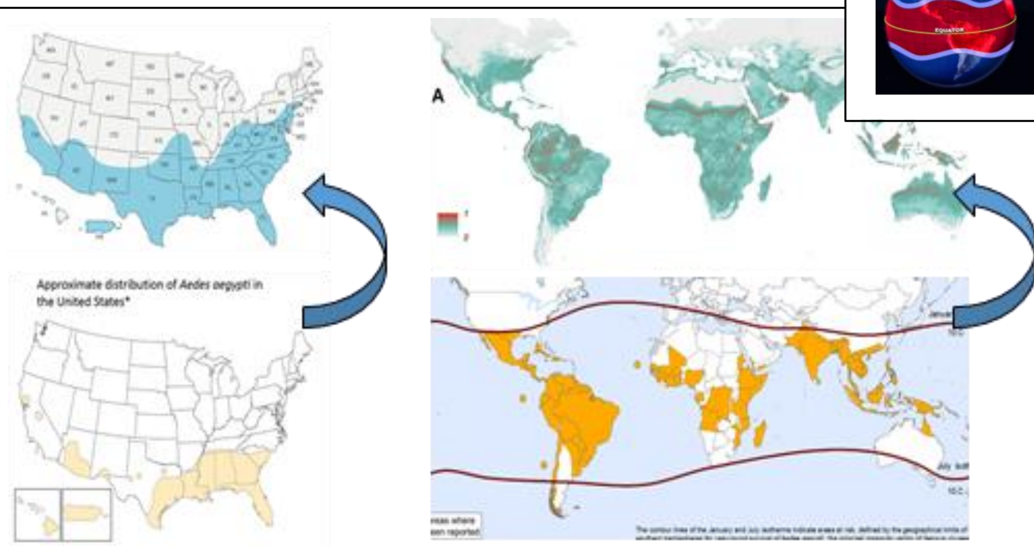


Fig. 16. The warming climate is moving the jet streams poleward (inset), expanding the tropical zone and moving the northern geographical limits of *Aedes aegypti* overwintering further northward.

Threats to National Security from climate change

U.S. military planners have long taken threats from climate change seriously and addressed them in forward plans for protection of national security. Dramatic effects on regional environmental conditions have had profound effects on the stability of governments that have involved the U.S. in costly military operations.

The Arab Spring (2011-2014) was immediately preceded by a once-a-century winto crop failure in China that inflated global wheat prices. The top 9 wheat importing countries are in the Middle East, and 7 of these had price protests involving deaths and ignited revolutions over pent-up stresses.

The Syrian civil war was entirely unexpected; that country with its educated population, steady economy and generally optimisic economic outlook was thought to be immune to the civil wars of its Middle East neighbors. However, the highly destructive civil war still in progress was preceded by 4 years of the worst drought and crop failure in its history. Crop losses reached 75%. Sheep herders lost 85% of their sheep. Hundreds of thousands of wells were drilled for water, draining the aquifers. These conditions caused a massive migration of rural populations to the cities, and poor government management led to open civil war.

The major economic powers, the U.S., Russia and China, are competing for control of commercial passages and mineral rights opened up by the melting Arctic ice.

Climate change is driving immigration from Central America to the U.S. border

Accelerating crop failures in Central America are accelerating northward immigration to the U.S. The most severely affected countries are Guatamala, El Salvador, Honduras, and Nicarogua (Fig. 17). By 2018, 29% of all asylum applications to all U.S. ports combined were from Guatamala, El Salvador and Honduras; only 7% were from Mexico (U.S.CIS report, April 2018). The U.N. Food and Agriculture Organization reports that 1.6 million Central Americans face food insecurity, and the World Food Program surveyed immigrants who recently left Central America and found that half had left because of lack of food.

Fig. 17. Central American countries currently experiencing severe, prolonged drought.

Climate change is thought to drive immigration from Central America both directly by its negative impact on the food supply and indirectly by driving migration from the dominant rural farming economiy to rapidly growing cities. There overcrowding and poverty fuel crime and exploitation, which out of fear drive immigration northward (Fig. 18).

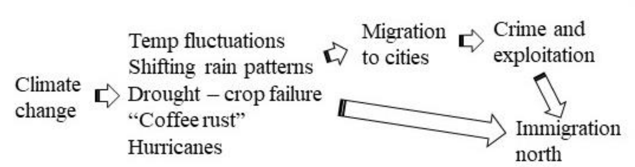


Fig. 18. How climate change is driving immigration both directly and indirectly from Central America northward.

Rising sea levels

One of the most widely publicized adverse effects of climate change, along with increasing forest fires and hurricanes, is rising sea levels. Since 1870 global mean sea level has steadily risen 3.3 mm per year, presently totaling 9 inches (230 mm).[4] Worldwide 8 of the 10 largest cities are located on the coastline and are experiencing increased flooding. In Miami street flooding at high tide that used to happen once or twice a year is now occurring many times a year, and property values and insurance rates are being affected. Many low-lying coastal regions and islands are facing inundation. In the U.S. approximately 40% of the population lives in relatively high-populatin-density coastal areas where rising sea level is causing increased flooding, shoreline erosion, and serious damage from storms.

There are 2 major causes of sea level rise: thermal expansion of sea water and melting of the land-based ice masses, mainly glaciers and ice sheets. At present 90% of increases in atmospheric heat from global warming is absorbed by the oceans. Thermal expansion accounted for most of the rise before the exponential rise in global temperatures in the early 1980s. Since then melting of land ice has accounted for 80%.

Melting ice sheets

The world has 3 massive ice sheets: the Arctic, Greenland and Antarctic ice sheets (Fig. 19). Together they contain approximately 80% of the world's fresh water. They have existed for approximately 34 million years. For decades scientists believed that ice sheet melting would happen slowly, giving us plenty of time to control global warming and curtail melting. However, in the past 3 years improved satellite imaging has revealed far more rapid melting of all 3 ice sheets. Melting of the Arctic ice sheet will not increase sea level directly since melting of floating ice does not increase sea level (more on this below), but melting of land-based ice will.

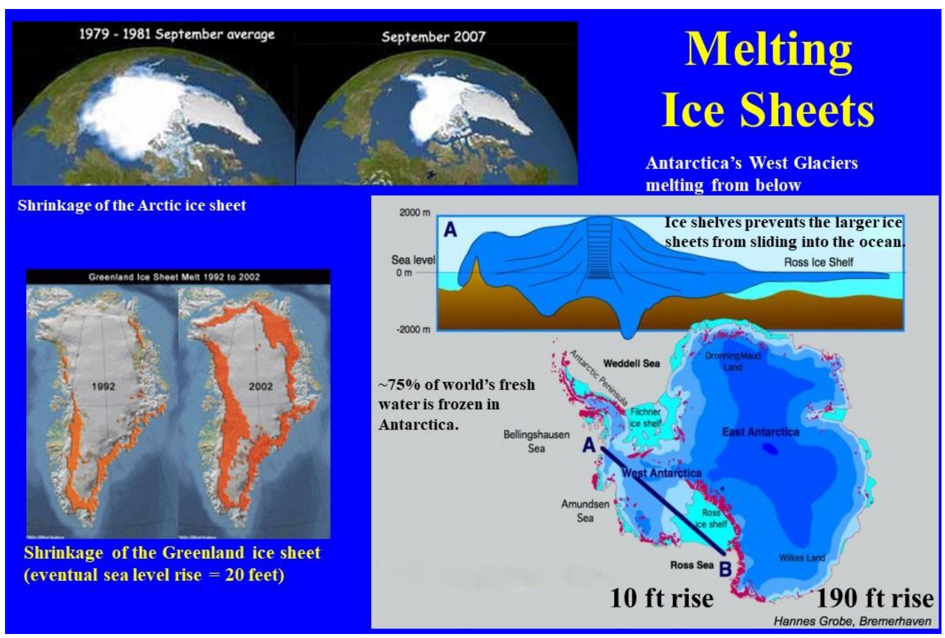


Fig. 19. Melting ice sheets. Complete melting of the land-based Greenland and Antarctic ice sheets would raise global mean sea level by approximately 220 ft. Melting of the floating Arctic ice will not raise sea levels directly.

The Antarctic ice mass is composed of the massive East Antarctica ice sheet and the thinner West Antarctica sheet. Scientists have been observing the progressive melting of the West Antarctica ice sheet for decades, as floating ice shelves at his periphery have been dropping off and large fissures have been appearing in its land-based ice sheet. Recent evidence indicates that the brittle ice shelves play a crucial role in stabilizing the ice sheets and preventing them from slipping into the ocean where they would melt rapidly. When West Antarctica melts completely, sea level is expected to rise an estimated 10 feet. New evidence now shows that the massive East Antarctic ice sheet, which was thought to be stable, is also losing ice more rapidly than previously thought. According to the National Snow and Ice Data Center, complete melting of the Greenland ice sheet would increase sea level by 20 feet, and of the East Antarctic ice sheet, by over 190 feet—a total of 220 ft altogether.

The dire effects of feedback

A critical unanswered question that gets to the issue of how fast global warming will progress is what explains the huge, rapid swings in the atmospheric CO_2 concentration that have ended every ice age for the past 34 million years (Fig. 20)? Where was all that carbon coming from, why was it releases so rapidly, what might trigger such a release now, and how much sequestered carbon is there? It had to have been from massive feedback between rising temperatures and biological ecosystems, triggered by unknown rapid increases in global temperature. Although such rapid shifts have been conjectured for decades, they have not yet been incorporated into the large super computer climate models used to predict the course of warming and climate change. If they were, projections would be more dire, with climate shifts sudden and large.

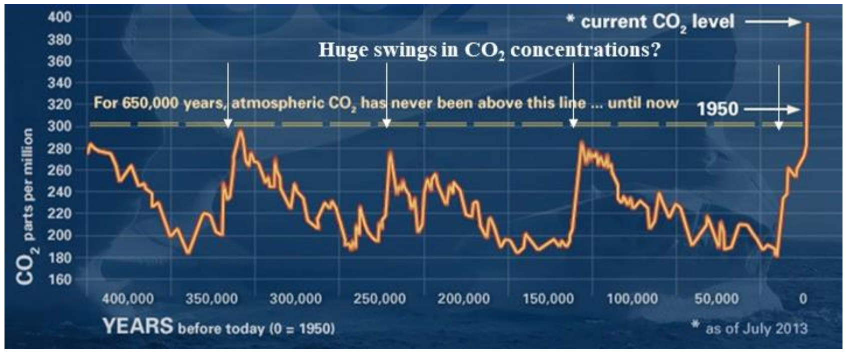


Fig. 20. What explains the huge, rapid swings in CO_2 (vertical arrows) that ended each ice age for the past 34 million years?

One example of positive feedback from global warming relates to the melting of snow and ice-covered land. White ice and snow-covered surfaces reflect sunlight back into space and counteract warming; whereas, dark land masses absorb more light energy. Melting ice exposes land, more light is absorbed, and melting accelerates. This exposes more land, which absorbs more light energy, and so on.

Another example involves the major role of vegetation in absorbing CO_2 and sequestering it underground in its root systems. When drought, fires or human development cause deforestation, the roots decompose and release sequestered carbon, mostly as methane (CH_4), which has 86 times the heat trapping potentcy of CO_2 in the short term. The resulting warming encourages more fires and thus more deforestation, and so on.

Melting of the Arctic permafrost

Permafrost is a thick layer, from several feet to a mile thick, composed of plant and animal matter deposited and frozen there over millions of years (Fig. 21). Permafrost covers approximately a quarter of the land mass of the Northern Hemisphere, stretching around the globe from Northern Canada to Northern Scandinavia and on to Siberia. Recall that global warming of these northern climes is 2-3 times that of lower latitudes and thus is melting the permafrost rapidly. The National Center for Atmospheric Research has estimated that up to 90% of the Northern Hemisphere's topmost layer of permafrost could thaw by 2100. When the vast amounts of organic matter thaw, they putrify, releasing huge amounts of CH_4 and CO_2 into the atmosphere, further warming the atmosphere.

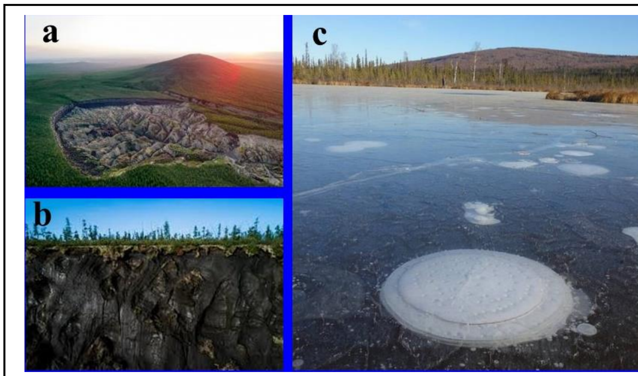


Fig. 21. Melting permafrost in Siberia. a) melting permafrost "crater". b) cross-section of Arctic permafrost containing frozen leaves, grass and animal matter frozen for millennia. c) methane bubbling up from a new Arctic lake in thawed Siberian tundra.

The Thermohaline Circulation and the polar ice sheets

In an effort to develop a better understanding of climate sensitivity to warming and thus to predict how rapidly global warming could accelerate and how climate will be affected, James Hansen, leading a multidisciplinary team of scientists, compiled the existing evidence on the rapid warming and CO_2 rise that ended the ice age 120,000 years ago and their effects on the climate of the ensuing interglacial temperate period (Fig. 22). They found, contrary to predictions, when global temperature reached only slightly higher than today, large chunks of polar ice disintegrated, producing a rapid rise in sea level of 20-30 ft. It has been generally agreed this will happen, but gradually over several centuries. The new finding is that it will happen more abruptly over the next 50 years, inundating most of the world's large coastal cities.

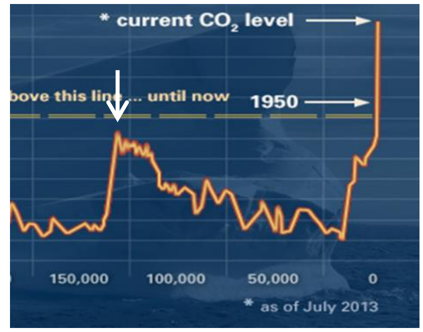


Fig. 22. The 2016 paper by James Hansen's team of multidisciplinary scientists to explain the rapid warming that ended the ice age 120,000 years ago (arrow).

The Thermohaline Circulation. Presently a massive underwater current in the Atlantic Ocean connects and sustains the large Arctic and Antarctic ice sheets (Fig. 23). Warm surface currents are driven northward by temperature and salinity gradients, cooling them en route. Reaching the Arctic Ocean, salinity increases and they become very cold and dense and sink to the bottom, forming the North Atlantic Deep Water, which flows southward. Reaching Antarctica, they circulate around the land mass, rise and maintain the cold temperature of the frozen Antarctic ice shelf.

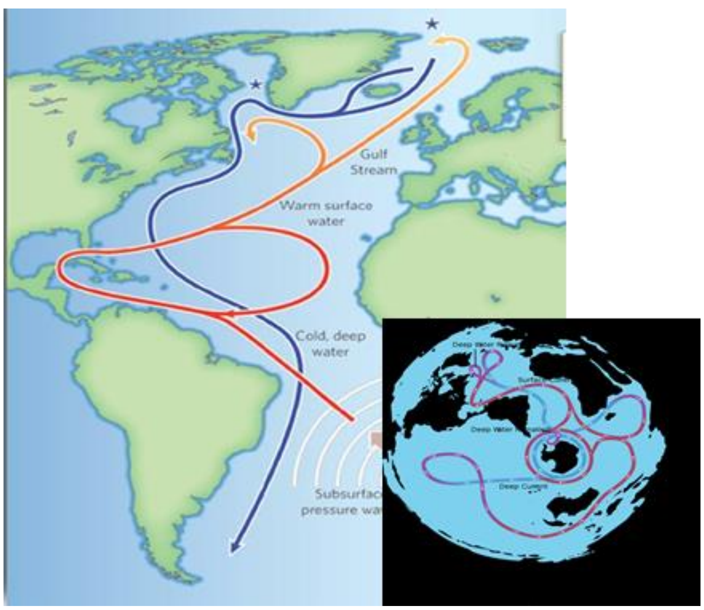


Fig. 23. The Thermohaline Circulation (the "Ocean Conveyor Belt") brings warm surface water northward to the Arctic where it cools and dives to the bottom, then transits southward to circle Antarctica, cooling and maintaining the Antarctic ice shelf.

The combined paleoclimatic and modern geological evidence suggests that 120,000 years ago the initial melting of the Arctic ice sheet released large caps of fresh water between the Arctic and Greenland. This slowed or stopped the Thermohaline Circulation that distributes heat around the planet and allows some of it to escape into space. Warmth then accumulated in the deeper ocean and greatly accelerated melting of the Antarctic ice sheets. Geological methods in the study found evidence of immense storms, many times stronger than storms during human history, simultaneous with the accelerated polar ice melt, driven by large north-south temperature gradients. During these

Fig. 24. Megaboulders at the crest of a 65 ft high ridge (person pictured for size perspective). Examination of underlying soil strata confirmed that the boulders were wave-transported.

storms massive bolders the size of buildings were thrown up onto cliffs above the shore by violent wave activity (Fig. 24).

Applied to the present, the Hansen team's evidence predicts abrupt catastrophic sea level rise and extremely violent storm activity by **50 years from now**.

This theory was raised and examined 10 years earlier with the existing research methods and found to overstate the degree of slowing of the ocean currents. But this new paper uses powerful new multidisciplinary research methods to generate novel evidence from geological history that reopens it.

How much sequestered carbon is there?

Since the end of the pre-industrial era humans have released into the atmosphere more carbon than had repetively been mobilized in the abrupt ending of past ice ages and forced the CO_2 level far above its highest level in millions of years (Figs. 8 and 22 above). This anthropogenic outpouring of CO_2 occurred in the present interglacial temperate era after the abrupt increase in atmosphieric CO_2 that ended the last ice age 11,000 years ago (Fig. 8). This raises the question of what positive feedback loops might now be triggered and whether there might be additional sequestered carbon sources ready to pour out into the atmosphere to further accelerate global warming.

Ice core and lakebed sediment core sampling have constucted a record of the atmospheric CO_2 levels back more than 500 million years (Fig. 25). It shows repeated spikes of CO_2 coinciding with the 5 mass extinctions of species.[14] Finally in the last 35 million years, the CO_2 level has declined to the temperate levels below 300 ppm characterized by the Glacial-Interglacial cycles (Fig. 8 above), formation of the polar ice sheets, and last, all of hominid evolution. Thus, humans have lived entirely in the lowest CO_2 environment of geological time. And yet, anthropogenic fossil fuel burning has produced CO_2 levels unseen throughout this temperate period. Were this stimulus to trigger some new biological feedback cycle for further release of long sequestered carbon, it is apparent that there are sufficient carbon sources, released in prior geologic epochs, that would extinguish human life.

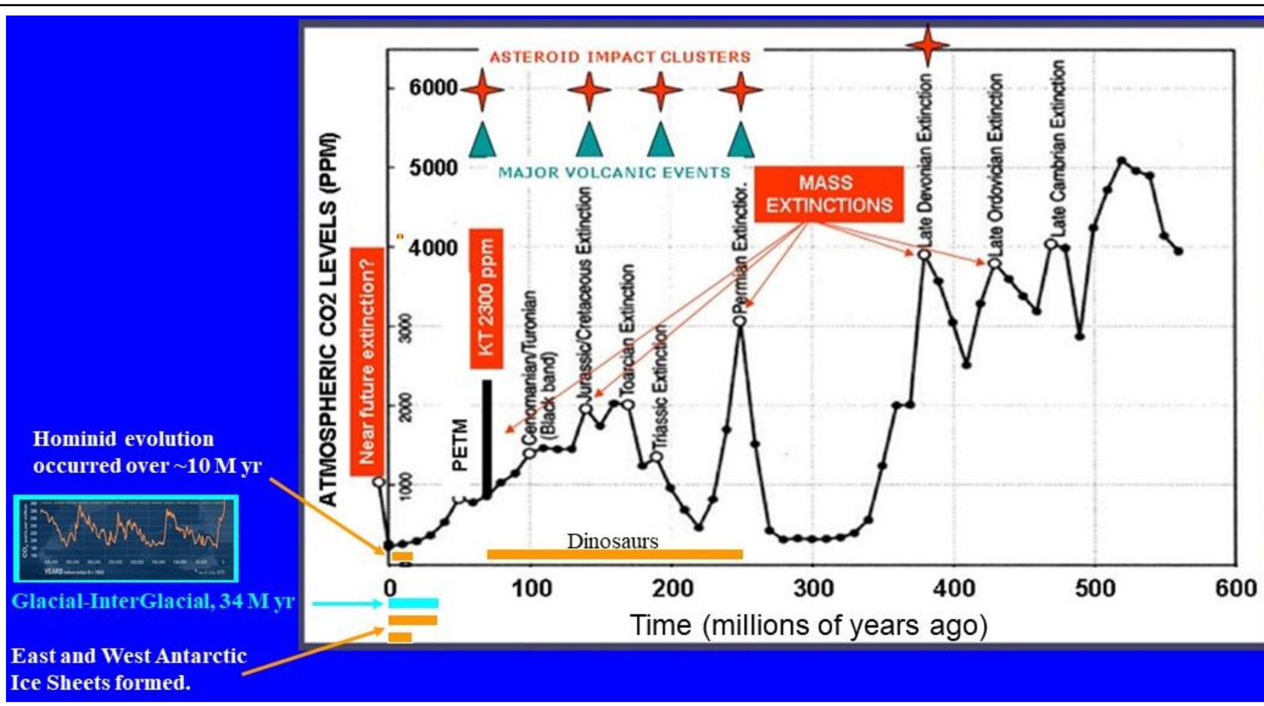


Fig. 25. Massive shifts in atmospheric CO_2 levels and mass extinctions of species through time when atmospheric CO_2 levels reached several thousand ppm (compared with a high of 415 ppm today).

The conclusion for question 3 "Is the warming climate a threat to humans?" is yes, global warming with climate change from human emissions of CO_2 and other greenhouse gases:

- *Is no longer a debate within the scientific world.*
- *Is not an issue of faith that you "believe in" or not.*
- *Is a rapidly growing threat to our children's future (Fig. 26).*
- *Can be constrained by action in the next 10 years.*

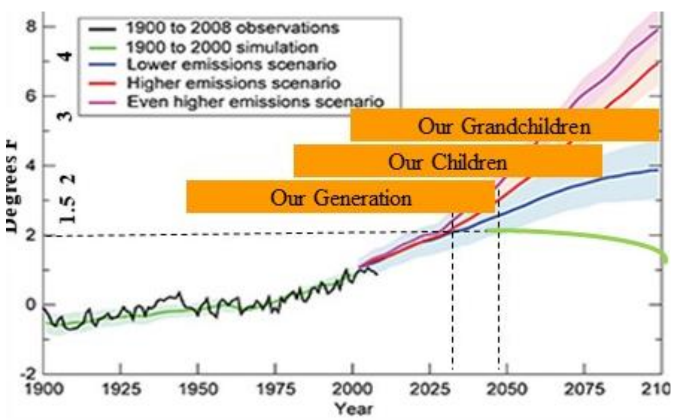


Fig. 26. Scenarios of climate sensitivity in relation to the life span of 3 generations alive today.

Q4. Should society invest in curtailing climate warming?

Transition to non-polluting sources of energy

Since CO_2 emissions stay in the atmosphere for centuries, we must phase out fossil fuel emissions by 2030. This must involve

- Transitioning to non-polluting renewables (solar, wind, and "traveling wave technology")
- Phase out coal extraction and fracking for oil and natural gas.
- Transition transportation to all-electric.
- Assist other major polluting countries to follow our lead.
- A carbon tax with rebate is the most efficient route to get there (William Nordhaus, 2018 Nobel Prize in Economics)

Traveling-wave technology

A potentially game-changing technology for clean energy generation is what is called "traveling wave reactor" (TWR) technology.[15] Though conceived decades earlier, Bill Gates selected it from many ideas he solicited and invested hundreds of millions to explore. He then formed a company TerraPower in 2007 to develop the idea to industrial scale. See new Netflix documentary (Fig. 27).

To exploit the enormous power of nuclear reactions but without the serious drawbacks of nuclear fission, TWR consists fundamentally of a cool reactor that "burns" nuclear waste that has been piling up at storage sites for decades to produce energy in a controlled process that cannot burn, explode or melt down. Basically enough spent nuclear fuel is loaded into the TWR reactor to power it fully for 40 years; a small seed of enriched uranium is added to start the reaction; and thereafter the small concentraton of fissile atoms remaining in the depleted uranium undergo limited fission in a wave that travels slowly through the load of fuel, generating energy in an entirely safe though powerful reaction.

There is enough spent nuclear fuel in the nation's nuclear waste dumps to power the entire country for 100 years, and the working reactor is relatively cheap and quick to build and put into operation without the costly regulatory approvals that delay and escalate building costs of traditional nuclear fission reactors. Powering TWR does not involve enriching uranium, so it can be readily shared with all countries with no threat of nuclear weapons proliferation.

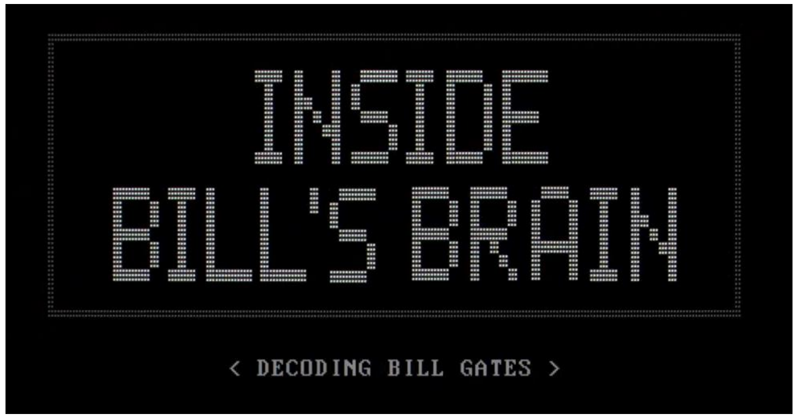


Fig. 27. Title frame from the new Netflix 3-part documentary which won Special Selection at the 2019 Telluride Film Festival. Part 3 recounts the idea generation, development and implementation of Traveling Wave Reactor technology by TerraPower.

TerraPower developed the concept to a working prototype at industrial scale by 2015, and had an agreement with a Chinese company to install the first working model in a demonstration project, when the recent trade war with China cancelled the project. The technology awaits government permission to proceed with final development.

Removal of existing CO_2 from the atmosphere

Even if we completely stop putting CO_2 into the atmosphere, atmospheric CO_2 levels would remain above 400 ppm for 2 centuries before the CO_2 degrades. The ongoing ice sheet loss and feedback systems would prove increasingly catastrophic. Technology exists to remove CO_2 from the air and either sequester it permanently underground or develop it into products to make the extraction process economical. However, large investments from the federal level are required to scale it up to industrial levels.

Enviromentalists have discouraged discussion of CO_2 removal for fear that it will provide a political excuse for not phasing our CO_2-emitting industries. However, it is essential to accompish both to avoid eventual catastrophic results.

The essential role of the federal government

While efforts at the individual and local/state levels are helpful and should be encouraged, they will not accomplish the goal alone. Only full commitment of the U.S. federal government, leading our domestic program and the world's other national governments, can get us to where we need to be (Paul Romer, 2018 Nobel Prize in Economics). The federal government is the collective force of all Americans to accomplish the greatest tasks that are beyond local or individual abilities. Federal leadership is essential to invest in rapidly developing to scale the required technologies and to lead and incentivize other countries to follow expeditiously.

To reiterate, there are only 2 unknowns in predicting how bad the climate situation will get: the sensitivity of the climate to the rise in greenhouse gas concentrations, and whether humans will take sufficient actions to curtain the problem. In the past several years, evidence has been growing that the climate is far more sensitive than assumed before and is likely to respond with consequences on the most severe end of all the modeled scenarios. Consequently, human action through national governments is the only force that will save the human species.

From the Ethics of Scientific Integrity: Skepticism vs Denialism

Definitions

> **Skepticism** = Withholding belief because the evidence does not live up to the standards of science.
> **Denialism** = Refusing to believe something in the face of what most other people would consider compelling evidence.

It is easy to confuse the two

- Withholding belief makes us feel rigorous and superior to those "naïve believers."
- No matter how strong the evidence, the scientists could be wrong.
- Denial may be necessary to belong to a social group or a political party.
- Wealthy fossil fuel interests have bombarded us with doubt about the science, much as the wealthy tobacco interests have.

But . . . when we withhold belief long past the point at which the overwhelming cascade of evidence should have convinced us, particularly when inertia will condemn our children and grandchildren to a miserable life, we have moved beyond skepticism to *willful ignorance* . . . *extreme gullibility*.

Conclusion

"What do we do about this monster that we have created, nourished, and developed to a point where its nefarious power today is literally a million times greater than in 1945? We all know that we are the first generation of humans since Genesis that can totally destroy the human species and make our beautiful planet uninhabitable."

Father Theodore J. Hesburgh
President Emeritus,
University of Notre Dame
May 12, 1988
From his speech "The Nuclear Dilemma: The Greatest Moral Problem of All Time"

. . . We are now the second generation of such humans.

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