STATE OF IOWA

BEFORE THE IOWA UTILITIES BOARD

IN RE: **INTERSTATE POWER AND LIGHT COMPANY**	**DOCKET NO. GCU-07-1**

DIRECT TESTIMONY OF JAMES E. HANSEN

Q. Please state your name and business address.

A. My name is James E. Hansen. My business address is 2880 Broadway, New York, New York 10025.

Q. By whom are you presently employed and in what capacity?

A. I am employed by the National Aeronautics and Space Administration (NASA) Goddard Space Flight Center (GSFC), which has its home base in Greenbelt Maryland. I am the director of the Goddard Institute for Space Studies (GISS), which is a division of GSFC located in New York City. I am also a senior scientist in the Columbia University Earth Institute and an Adjunct Professor of Earth and Environmental Sciences at Columbia. I am responsible for defining the research direction of the Goddard Institute, obtaining research support for the Institute, carrying out original scientific research directed principally toward understanding global change, and providing relevant information to the public. I am testifying here as a private citizen, a resident of Kintnersville Pennsylvania on behalf of the planet, of life on Earth, including all species.

Q. What is your educational background?

A. I was trained in physics and astronomy at the University of Iowa in the space science program of Professor James Van Allen. I have a bachelors degree in physics and mathematics, a masters degree in astronomy, and a Ph.D. in physics, all from the University of Iowa. I also did research as a graduate student at the Universities of Kyoto and Tokyo, and I was a post-doctoral fellow of the United States National Science Foundation studying at the Sterrewacht, Leiden University, Netherlands, under Prof. Henk van de Hulst.

Q. Please describe your professional experience.

A. Upon graduating from the University of Iowa in February 1967 I joined the Goddard Institute for Space Studies, where I have been ever since, except for 1969 when I was a post-doctoral fellow in the Netherlands. In my first ten years at the Goddard Institute I focused on planetary research. I was Principal Investigator for an experiment on the Pioneer Venus spacecraft to study the clouds of Venus and I was involved in other planetary missions. In the mid-1970s, as evidence of human-made effects on Earth's atmosphere and climate became apparent, I began to spend most of my time in research on the Earth's climate. I became director of the Goddard Institute in 1981, focusing the Institute's program on global change, while maintaining a broad perspective from planetary studies and the Earth's history.

Q. What is the purpose of your testimony?

A. My aim is to present clear scientific evidence describing the impact that coal-fired power plants (without carbon capture and storage) will have on the Earth's climate, and thus on the well-being of today's and future generations of people and all creatures and species of creation.

Burning of fossil fuels, primarily coal, oil and gas, increases the amount of carbon dioxide (CO_2) and other gases and particles in the air. These gases and particles affect the Earth's energy balance, changing both the amount of sunlight absorbed by the planet and the emission of heat (long wave or thermal radiation) to space. The net effect is a global warming that has become substantial during the past three decades.

Global warming from continued burning of more and more fossil fuels poses clear dangers for the planet and for the planet's present and future inhabitants. Coal is the largest contributor to the human-made increase of CO_2 in the air. Saving the planet and creation surely requires phase-out of coal use except where the CO_2 is captured and sequestered (stored in one of several possible ways).

Q. Coal is only one of the fossil fuels. Can such a strong statement specifically against coal be justified, given still-developing understanding of climate change?

A. Yes. Coal reserves contain much more carbon than do oil and natural gas reserves, and it is impractical to capture CO_2 emissions from the tailpipes of vehicles. Nor is there any prospect that Saudi Arabia, Russia, the United States and other major oil-producers will decide to leave their oil in the ground. Thus unavoidable CO_2 emissions in the next few decades will take atmospheric CO_2 amounts close to, if not beyond, the level needed to cause dangerous climate change. The only practical way to prevent CO_2 levels from going far into the dangerous range, with disastrous effects for humanity and other inhabitants of the planet, is to phase out use of coal except at power plants where the CO_2 is captured and sequestered.

Q. But why focus on a coal plant in Iowa? Coal-fired power plants are being built at a much faster rate in China.

A. The United States is responsible for more than three times as much of the excess CO_2 in the air than any other country. The United States and Europe together are responsible for well over half of the increase from the pre-industrial CO_2 amount (280 ppm, ppm = parts per million) to the present-day CO_2 amount (about 385 ppm). The United States will continue to be most responsible for the human-made CO_2 increase for the next few decades, even though China's ongoing emissions will exceed those of the United States. Although a portion of human-made CO_2 emissions is taken up by the ocean, there it exerts a 'back pressure' on the atmosphere, so that, in effect, a substantial fraction of past emissions remains in the air for many centuries, until it is incorporated into ocean sediments. Furthermore, even as China's emissions today approximately equal those of the United States, China's per capita CO_2 emissions are only about 20% of those in the United States.

China, India and other developing countries must be part of the solution to global warming, and surely they will be, if developed countries take the appropriate first steps. China and India have the most to lose from uncontrolled climate change, as they have huge populations living near sea level, and they have the most to gain from reduced local air pollution. Analogous to the approach of the Montreal Protocol, developing countries, with technical assistance, will need to reduce their emissions soon after the developed world reduces its emissions.

Furthermore, it makes economic sense for the United States to begin strong actions now to reduce emissions. Required technology developments in efficiency, renewable energies, truly clean coal, biofuels, and advanced nuclear power will produce good high-tech jobs and provide a basis for international trade that allows recovery of some of the wealth that the country has been hemorrhaging to China.

Q. How can one power plant in Iowa be of any significance in comparison with many power-plants in China?

A. The Iowa power plant can make an important difference because of tipping points in the climate system, tipping points in life systems, and tipping points in social behavior. A tipping point occurs in a system with positive feedbacks. When forcing toward a change, and change itself, become large enough, positive feedbacks can cause a sudden acceleration of change with very little, if any, additional forcing.

Arctic sea ice is an example of a tipping point in the climate system. As the warming global ocean transports more heat into the Arctic, sea ice cover recedes and the darker open ocean surface absorbs more sunlight. The ocean stores the added heat, winter sea ice is thinner, and thus increased melting can occur in following summers, even though year-to-year variations in sea ice area will occur with fluctuations of weather patterns and ocean heat transport.

Arctic sea ice loss can pass a tipping point and proceed rapidly. Indeed, the Arctic sea ice tipping point has been reached. However, the feedbacks driving further change are not ‘runaway’ feedbacks that proceed to loss of all sea ice without continued forcing. Furthermore, sea ice loss is reversible. If human-made forcing of the climate system is reduced, such that the planetary energy imbalance becomes negative, positive feedbacks will work in the opposite sense and sea ice can increase rapidly, just as sea ice decreased rapidly when the planetary energy imbalance was positive.

Planetary energy imbalance can be discussed quantitatively later, including all of the factors that contribute to it. However, it is worth noting here that the single most important action needed to decrease the present large planetary imbalance driving climate change is curtailment of CO_2 emissions from coal burning. Unless emissions from coal burning are reduced, actions to reduce other climate forcings cannot stabilize climate.

The most threatening tipping point in the climate system is the potential instability of large ice sheets, especially West Antarctica and Greenland. If disintegration of these ice sheets passes their tipping points, dynamical collapse of the West Antarctic ice sheet and part of the Greenland ice sheet could proceed out of our control. The ice sheet tipping point is especially dangerous because West Antarctica alone contains about 20 feet (6 meters) of sea level rise.

Hundreds of millions of people live within 20 foot elevation of sea level. Thus the number of people affected would be 1000 times greater than in the New Orleans Katrina disaster. Although Iowa would not be directly affected by sea level rise, repercussions would be worldwide.

Ice sheet tipping points and disintegration necessarily unfold more slowly than for sea ice, on time scales of decades to centuries, because of the greater inertia of thick ice sheets. But that inertia is not our friend, as it also makes ice sheet disintegration more difficult to halt once it gets rolling. Moreover, unlike sea ice cover, ice sheet disintegration is practically irreversible. Nature requires thousands of years to rebuild an ice sheet. Even a single millennium, about 30 generations for humans, is beyond the time scale of interest or comprehension to most people.

Because of the danger of passing the ice sheet tipping point, even the emissions from one Iowa coal plant, with emissions of 5,900,000 tons of CO_2 per year and 297,000,000 over 50 years could be important as "the straw on the camel's back". The Iowa power plant also contributes to tipping points in life systems and human behavior.

Q. How can Iowa contribute to tipping points in life systems and human behavior?

There are millions of species of plants and animals on Earth. These species depend upon each other in a tangled web of interactions that humans are only beginning to fathom. Each species lives, and can survive, only within a specific climatic zone. If climate changes, species migrate in an attempt to stay within their livable range. However, large rapid climate change can drive most of the species on the planet to extinction. Geologic records indicate that mass extinctions, with loss of more than half of existing species, occurred several times in the Earth's history. New species developed, but that required hundreds of thousands, even millions, of years. If we destroy a large portion of the species of creation, those that have existed on Earth in recent millennia, the Earth will be a far more desolate planet for as many generations of humanity as we can imagine.

Today, as global temperature is increasing at a rate of about 0.2°C (0.36°F) per decade, isotherms (a line of a given average temperature) are moving poleward at a rate of about 50-60 km (35 miles) per decade. Some species are moving, but many can move only slowly, pathways may be blocked as humans have taken over much of the planet, and species must deal with other stresses that humans are causing. If the rate of warming continues to accelerate, the cumulative effect this century may result in the loss of a majority of existing species.

The biologist E.O. Wilson explains that the 21st century is a "bottleneck" for species, because of extreme stresses they will experience, most of all because of climate change. He foresees a brighter future beyond the fossil fuel era, beyond the peak human population that will occur if developing countries follow the path of the developed world to lower fertility rates. Air and water can be clean and we can learn to live with other species of creation in a sustainable way, using renewable energy. The question is: how many species will survive the pressures of the 21st century bottleneck? Interdependencies among species, some less mobile than others, can lead to collapse of ecosystems and rapid nonlinear loss of species, if climate change continues to increase.

Coal will determine whether we continue to increase climate change or slow the human impact. Increased fossil fuel CO_2 in the air today, compared to the pre-industrial atmosphere, is due 50% to coal, 35% to oil and 15% to gas. As oil resources peak, coal will determine future CO_2 levels. Recently, after giving a high school commencement talk in my hometown, Denison, Iowa, I drove from Denison to Dunlap, where my parents are buried. For most of 20 miles there were trains parked, engine to caboose, half of the cars being filled with coal. If we cannot stop the building of more coal-fired power plants, those coal trains will be death trains – no less gruesome than if they were boxcars headed to crematoria, loaded with uncountable irreplaceable species.

So, how many of the exterminated species should be blamed on the 297,000,000 tons of CO_2 that will be produced in 50 years by the proposed Sutherland Generating Station Unit 4 powerplant? If the United States and the rest of the world continue with "business-as-usual" increases in CO_2 emissions, a large fraction of the millions of species on Earth will be lost and it will be fair to assign a handful of those to Sutherland Generating Station Unit 4, even though we cannot assign responsibility for specific species. Moreover, the effect of halting construction of this power plant potentially could be much greater, because of the possibility of positive feedbacks among people.

Q. What tipping points in human behavior are you referring to?

A. As the reality of climate change becomes more apparent, as the long-term consequences of further climate change are realized, and as the central role of coal in determining future atmospheric CO_2 is understood, the pressures to use coal only at power plants where the CO_2 is captured and sequestered will increase. If the public begins to stand up in a few places and successfully oppose the construction of power plants that burn coal without capturing the CO_2, this may begin to have a snowball effect, helping utilities and politicians to realize that the public prefers a different path, one that respects all life on the planet.

The changes in behavior will need to run much broader and deeper than simply blocking new dirty coal plants. Energy is essential to our way of life. We will have to find ways to use energy more efficiently and develop renewable and other forms of energy that produce little if any greenhouse gases. The reward structure for utilities needs to be changed such that their profits increase not in proportion to the amount of energy sold, but rather as they help us achieve greater energy and carbon efficiency. As people begin to realize that life beyond the fossil fuel era promises to be very attractive, with a clean atmosphere and water, and as we encourage the development of the technologies needed to get us there, we should be able to move rapidly toward that goal. But we need tipping points to get us rolling in that direction.

Iowa, and this specific case, can contribute to the tipping points. A message that 'old-fashioned' power plants, i.e., those without carbon capture and sequestration, are no longer acceptable, would be a message of leadership, one that would be heard beyond the state's borders.

Q. The alleged implications of continued coal burning without carbon capture are profound and thus require rigorous quantitative proof of relevant causal relationship between the CO_2 emissions and climate change. What is the nature of recent global temperature change?

A. Figure 1(a) shows global mean surface temperature change over the period during which instrumental measurements are available for most regions of the globe. The warming since the beginning of the 20th century has been about 0.8°C (1.4°F), with three-quarters of that warming occurring in the past 30 years

Q. Warming of 0.8°C (1.4°F) does not seem very large. It is much smaller than day to day weather fluctuations. Is such a small warming significant?

A. Yes, and it is important. Chaotic weather fluctuations make it difficult for people to notice changes of underlying climate (the average weather, including statistics of extreme fluctuations), but it does not diminish the impact of long-term climate change.

First, we must recognize that global mean temperature changes of even a few degrees or less can cause large climate impacts. Some of these impacts are associated with climate tipping points, in which large regional climate response happens rapidly as warming reaches critical levels. Already today's global temperature is near the level that will cause loss of all Arctic sea ice. Evidence suggests that we are also nearing the global temperature level that will cause the West Antarctic ice sheet and portions of the Greenland ice sheet to become unstable, with potential for very large sea level rise.

Second, we must recognize that there is more global warming "in the pipeline" due to gases humans have already added to the air. The climate system has large thermal inertia, mainly due to the ocean, which averages 4 km (about 2.5 miles) in depth. Because of the ocean's inertia, the planet warms up slowly in response to gases that humans are adding to the atmosphere. If atmospheric CO_2 and other gases stabilized at present amounts, the planet would still warm about 0.5C (about 1°F) over the next century or two. In addition, there are more gases "in the pipeline" due to existing infrastructure such as powerplants and vehicles on the road. Even as the world begins to address global warming with improved technologies, the old infrastructure will add more gases, with still further warming of the order of another 1°F.

Third, eventual temperature increases will be much larger in critical high latitude regions than they are on global average. High latitudes take longer to reach their equilibrium (long-term) response because the ocean mixes more deeply at high latitudes and because positive feedbacks increase the response time there (Hansen et al., 1984). Amplification of high latitude warming is already beginning to show up in the Northern Hemisphere. Figure 1(b) is the geographical pattern of mean temperature anomalies for the first six years of the 21st century, relative to the 1951-1980 base period. Note that warming over land areas is larger than global mean warming, an expected consequence of the large ocean thermal inertia. Warming is larger at high latitudes than low latitudes, primarily because of the ice/snow albedo feedback. Warming is larger in the Northern Hemisphere than in the Southern Hemisphere, primarily because of greater ocean area in the Southern Hemisphere, and the fact that the entire Southern Ocean surface around Antarctica is cooled by deep mixing. Also human-caused depletion of stratospheric ozone, a greenhouse gas, has reduced warming over most of Antarctica. This ozone depletion and CO_2 increase have cooled the stratosphere, increased zonal winds around Antarctica, and thus warmed the Antarctic Peninsula while limiting warming of most of the Antarctic continent (Thompson and Solomon, 2002; Shindell and Schmidt, 2004).

Until the past several years, warming has also been very limited in Southern Greenland and the North Atlantic Ocean just southeast of Greenland, probably because of the deep ocean mixing that occurs in a limited region there. However, with increasing loss of Arctic sea ice in recent years, Greenland warming is approaching that at similar latitudes in the Northern Hemisphere. On the long run, warming in the high latitude regions of the ice sheets in both hemispheres is expected to be at least twice as large as the global warming. The amplification of climate change at high latitudes has practical consequences for the entire globe, especially from the effects on ice sheets and sea level. High latitude amplification of global warming is expected on theoretical grounds, it is found in climate models, and it is confirmed in paleoclimate (ancient climate) records.

Q. **But those paleoclimate records show that the Earth's climate has changed by very large amounts many times in the past. For that reason, the NASA Administrator has suggested that we may not need to "wrestle" with human-made climate change. How do you reach a contrary conclusion?**

A. Paleoclimate data, indeed, reveal large climate changes. But that history of ancient climate changes shows that modest forcing factors can produce large climate change. In fact, paleoclimate data provide our most accurate and certain measure of how sensitive global climate is to climate forcings, including human-made climate forcings.

Q. **What is a climate forcing?**

A. A climate forcing is an imposed perturbation to the Earth's energy balance, which would tend to alter the planet's temperature. For example, if the sun were to become 1% brighter, that would be a forcing somewhat more than +2 W/m^2, because the Earth absorbs about 238 W/m^2 of energy from the sun. An increase of greenhouse gases, which absorb terrestrial heat radiation and thus warm the Earth's surface, is also a positive forcing. Doubling the amount of CO_2 in the atmosphere is a forcing of about 4 W/m^2.

Q. How large are natural climate variations?

A. That depends on the time scale. A useful time scale to examine is the past several hundred thousand years. There is good data for the temperature, changes of atmospheric composition, and the most important changes on the Earth's surface. Specifically, we know the amount of long-lived greenhouse gases, CO_2, CH_4 and N_2O, as a function of time from air bubbles in the ice sheets. Ice sheets are formed by snowfall that piles up year by year and compresses into ice as the weight of snow above increases. The date when the snow fell is known accurately for about the past 15,000 years from counting annual layers marked by summer crusting. Annual layers can be clearly distinguished in the upper part of the ice sheet. Less precise ways of dating ice layers are available for the entire depth of the ice sheets. The temperature when the snow flakes fell is inferred from the isotopic composition of the ice.

Figure 2 shows the temperature on the Antarctic ice sheet for the past 425,000 years. Similar curves are found from Greenland and from alpine ice cores, as well as from ocean sediment cores. Layered ocean sediments contain the shells of microscopic animals that lived in the ocean, the proportion of elements in these microscopic shells providing a measure of the ocean temperature at the time the animals lived. Swings of temperature from warm interglacial periods to ice ages occur world wide, with the glacial-interglacial temperature range being typically 3-4°C in the tropics, about 10°C at the poles, and about 5°C on global average.

We live today in a warm interglacial period, the Holocene, now almost 12,000 years in duration. The last ice age peaked about 20,000 years ago. Global mean temperature was about 5°C colder than today, with an ice sheet more than a mile thick covering Canada and reaching into the United States, covering the present sites of Seattle, Minneapolis, and New York. So much water was locked in this ice sheet, and other smaller ice sheets, that sea level was 110-130 meters (about 350-400 feet) lower during the ice age, thus exposing large areas of continental shelves.

Figure 3 shows that large changes of sea level are the norm as climate changes. Global sea level, global temperature, and atmospheric greenhouse gas amounts are obviously very highly correlated.

Q. The sea level changes are enormous. Is sea level always changing? What have the consequences been?

A. On millennial time scales resolvable in this graph, sea level, CO_2 and global temperature change together. However, close examination shows that sea level has been stable for about the past 7000 years. In that period the planet has been warm enough to prevent an ice sheet from forming on North America, but cool enough for the Greenland and Antarctic ice sheets to be stable. The fact that the Earth cooled slightly over the past 8000 years probably helped to stop further sea level rise.

Sea level stability played a role in the emergence of complex societies. Day et al. (2007) point out that when sea level was rising at the rate of 1 meter per century or faster biological productivity of coastal waters was limited. Thus it is not surprising that when the world's human population abandoned mobile hunting and gathering in the Neolithic (12,000-7000 years ago) they gathered in small villages in foothills and mountains. Day et al. note that within 1000 years of sea level stabilization, urban (>2500 people) societies developed at many places around the world (Figure 4). With the exception of Jericho, on the Jordan River, all of these first urban sites were coastal, where high protein food sources aided development of complex civilizations with class distinctions.

Modern societies have constructed enormous infrastructure on today's coastlines. More than a billion people live within 25 meter elevation of sea level. This includes practically the entire nation of Bangladesh, almost 300 million Chinese, and large populations in India and Egypt, as well as many historical cities in the developed world, including major European cities, many cities in the Far East, all major East Coast cities in the United States, among hundreds of other cities in the world.

Q. How much will sea level rise if global temperature increases several degrees?

A. Our best guide for the eventual long-term sea level change is the Earth's history. The last time the Earth was 2-3°C warmer than today, about 3 million years ago, sea level was about 25 meters higher. The last time the planet was 5°C warmer, just prior to the glaciation of Antarctica about 35 million years ago, there were no large ice sheets on the planet. Given today's ocean basins, if the ice sheets melt entirely, sea level will rise about 70 meters (about 230 feet).

The main uncertainty about future sea level is the rate at which ice sheets melt. This is a "nonlinear" problem in which positive feedbacks allow the possibility of sudden ice sheet collapse and rapid sea level rise. Initial ice sheet response to global warming is necessarily slow, and it is inherently difficult to predict when rapid change would begin. I have argued (Hansen, 2005, 2007) that a "business-as-usual" growth of greenhouse gases would yield a sea level rise this century of more than a meter, probably several meters, because practically the entire West Antarctic and Greenland ice sheets would be bathed in meltwater during an extended summer melt season.

The Intergovernmental Panel on Climate Change (IPCC, 2007) calculated a sea level rise of only 21-51 cm by 2095 for "business-as-usual" scenarios A2 and A1B, but their calculation included only thermal expansion of the ocean and melting of alpine glaciers, thus omitting the most critical component of sea level change, that from ice sheets. IPCC noted the omission of this component in its sea level projections, because it was unable to reach a consensus on the magnitude of likely ice sheet disintegration. However, much of the media failed to note this caveat in the IPCC report.

Earth's history reveals many cases when sea level rose several meters per century, in response to forcings much weaker than present human-made climate forcings. Iceberg discharge from Greenland and West Antarctica has recently accelerated. It is difficult to say how fast ice sheet disintegration will proceed, but this issue provides strong incentive for policy makers to slow down the human-made experiment with our planet.

Knowledge of climate sensitivity has improved markedly based on improving paleoclimate data. The information on climate sensitivity, combined with knowledge of how sea level responded to past global warming, has increased concern that we could will to our children a situation in which future sea level change is out of their control.

Q. How can the paleoclimate data reveal the climate sensitivity to forcings?

A. We compare different climate states in the Earth's history, thus obtaining a measure of how much climate responded to climate forcings in the past. In doing this, we must define climate forcings and climate feedbacks clearly. Alternative choices for forcings and feedbacks are appropriate, depending on the time scale of interest.

A famous definition of climate sensitivity is from the 'Charney' problem, in which it is assumed that the distributions of ice sheets and vegetation on the Earth's surface are fixed and the question is asked: how much will global temperature increase if the amount of CO_2 in the air is doubled? The Charney climate sensitivity is most relevant to climate change on the decadal time scale, because ice sheets and forest cover would not be expected to change much in a few decades or less. However, the Charney climate sensitivity must be recognized as a theoretical construct. Because of the large thermal inertia of the ocean, it would require several centuries for the Earth to achieve its equilibrium response to doubled CO_2, and during that time changes of ice sheets and vegetation could occur as 'feedbacks', i.e., as responses of the climate system that engender further climate change. Feedbacks can either magnify or diminish climate changes, these effects being defined as positive and negative feedbacks, respectively.

Climate feedbacks include changes of atmospheric gases and aerosols (fine particles in the air). Gases that change in response to climate change include water vapor, but also the long-lived greenhouse gases, CO_2, CH_4 and N_2O.

Q. Is water vapor not a stronger greenhouse gas than these others?

A. Yes, and that is sometimes a source of confusion. Water vapor readily evaporates into and condenses out of the atmosphere. The amount of H_2O in the air is a function of the climate, primarily a function of temperature. The air holds more water vapor in the summer than in winter, for example. Water vapor is a prime example of what we call 'fast' feedbacks, those feedbacks that respond promptly to changes of climate. Because H_2O causes a strong greenhouse effect, and tropospheric H_2O increases with temperature, it provides a positive feedback.

The Charney climate sensitivity includes the effects of fast feedbacks such as changes of water vapor and clouds, but it excludes slow feedbacks such as ice sheets. We obtain an empirical measure of the Charney climate sensitivity by comparing conditions on Earth during the last ice age, about 20,000 years ago with the conditions in the present interglacial period prior to major human-made effects. Averaged over a period of say 1000 years, the planet in each of these two states, glacial and interglacial, had to be in energy balance with space within a small fraction of 1 W/m^2. Because the amount of incoming sunlight was practically the same in both periods, the 5°C difference in global temperature between the ice age and the interglacial period had to be maintained by differences in atmospheric composition and changes of the surface boundary conditions. Both of these are well known.

Figure 5 shows that there was less of the long-lived greenhouse gases in the air during the last ice age. These gases affect the amount of thermal radiation to space, and they have a small impact on the amount of absorbed solar energy. We can compute the climate forcing due to the glacial-interglacial change of CO_2, CH_4, and N_2O with high accuracy. The effective climate forcing (Hansen et al. 2005), including the indirect effect of CH_4 on other gases, is 3 ± 0.5 W/m^2.

Changes on the Earth's surface also alter the energy balance with space. The greatest change is due to the large ice sheets during the last ice age, whose high albedo ('whiteness' or reflectivity) caused the planet to absorb less solar radiation. Smaller effects were caused by the altered vegetation distribution and altered shorelines due to lower sea level during the ice age. The climate forcing due to all these surface changes is 3.5 ± 1 W/m^2 (Hansen et al. 1984).

Thus the glacial-interglacial climate change of 5°C was maintained by a forcing of about 6.5 W/m^2, implying a climate sensitivity of about ¾°C per W/m^2. This empirical climate sensitivity includes all fast feedbacks that exist in the real world, including changes of water vapor, clouds, aerosols, and sea ice. Doubled CO_2 is a forcing of 4 W/m^2, so the Charney climate sensitivity is 3 ± 1 W/m^2 for doubled CO_2. Climate models yield a similar value for climate sensitivity, but the empirical result is more precise and it surely includes all real world processes with 'correct' physics.

Q. This climate sensitivity was derived from two specific points in time. How general is the conclusion?

A. We can check climate sensitivity for the entire past 425,000 years. Ice cores (Figure 5) provide a detailed record of long-lived greenhouse gases. A measure of surface conditions is provided by sediment cores from the Red Sea (Siddall et al. 2003) and other places, which yield a record of sea level change (Figure 6a). Sea level tells us how large the ice sheets were, because water that was not in the ocean was locked in the ice sheets. Greenhouse gas and sea level records allow us to compute the climate forcings due to both atmospheric and surface changes for the entire 425,000 years (Hansen et al. 2007a).

When the sum of greenhouse gas and surface albedo forcings (Figure 6b) is multiplied by the presumed climate sensitivity of ¾°C per W/m^2 the result is in remarkably good agreement with 'observed' global temperature change (Figure 6c) implied by Antarctic temperature change. Therefore this climate sensitivity has general validity for this long period. This is the Charney climate sensitivity, which includes fast feedback processes but specifies changes of greenhouse gases and surface conditions.

It is important to note that these changing boundary conditions (the long-lived greenhouse gases and surface albedo) are themselves feedbacks on long time scales. The cyclical climate changes from glacial to interglacial times are driven by very small forcings, primarily by minor perturbations of the Earth's orbit about the sun and by the tilt of the Earth's spin axis relative to the plane of the orbit.

Q. Can you clarify cause and effect for these natural climate changes?

A. Figure 7 is useful for that purpose. It compares temperature change in Antarctica with the greenhouse gas forcing. Temperature and greenhouse gas amounts are obtained from the same ice core, which reduces uncertainty in their sequencing despite substantial uncertainty in absolute dating. There is still error in dating temperature change relative to greenhouse gas change, because of the time needed for ice core bubble closure. However, that error is small enough that we can infer, as shown in Figure 7b, that the temperature change tends to slightly precede (by several hundred years) the greenhouse gas changes. Similarly, although the relative dating of sea level and temperature changes are less accurate, it is clear that warming usually precedes ice melt and sea level rise.

These sequencings are not surprising. They show that greenhouse gas changes and ice sheet area changes act as feedbacks that amplify the very weak forcings due to Earth orbital changes. The climate changes are practically coincident with the induced changes of the feedbacks (Figure 7). The important point is that the mechanisms for the climate changes, the mechanisms substantially affecting the planet's radiation balance and thus the temperature, are the atmospheric greenhouse gases and the surface albedo. Earth orbital changes induce these mechanisms to change, for example, as the tilt of the spin axis increases both poles are exposed to increased sunlight. Changed insolation affects the melting of ice and, directly and indirectly, the uptake and release of greenhouse gases.

Q. What is the implication for the present era and the role of humans in climate?

A. The chief implication is that humans have taken control of global climate. This follows from Figure 8, which extends records of the principal greenhouse gases to the present. CO_2, CH_4 and N_2O (not shown) are far outside their range of the past 750,000 years for which ice core records of atmospheric composition are available.

Q. Yet the global warming also shown in Figure 8 does not seem to be commensurate with the greenhouse gas increases, if we were to use the paleoclimate as a guide. Can you explain that?

A. Yes. Observed warming is in excellent agreement with climate model calculations for observed greenhouse gas changes. Two factors must be recognized.

First, the climate system has not had enough time to fully respond to the human-made climate forcings. The time scale after 1850 is greatly expanded in Figure 8. The paleoclimate portion of the graph shows the near-equilibrium (~1000 year) response to slowly changing forcings. In the modern era, most of the net human-made forcing was added in the past 30 years, so the ocean has not had time to fully respond and the ice sheets are just beginning to respond to the present forcing.

Second, the climate system responds to the net forcing, which is only about half as large as the greenhouse gas forcing. The net forcing is reduced by negative forcings, especially human-made aerosols (fine particles).

Q. But is not the natural system driving the Earth toward colder climates?

A. If there were no humans on the planet, the long term trend would be toward colder climate. However, the two principal mechanisms for attaining colder climate would be reduced greenhouse gas amounts and increased ice cover. The feeble natural processes that would push these mechanisms in that direction (toward less greenhouse gases and larger ice cover) are totally overwhelmed by human forcings. Greenhouse gas amounts are skyrocketing out of the normal range and ice is melting all over the planet. Humans now control global climate, for better or worse.

Another ice age cannot occur unless humans go extinct, or unless humans decide that they want an ice age. However, ‘achieving’ an ice age would be a huge task. In contrast, prevention of an ice age is a trivial task for humans, requiring only a ‘thimbleful’ of CFCs (chlorofluorocarbons), for example. The problem is rather the opposite, humans have already added enough greenhouse gases to the atmosphere to drive global temperature well above any level in the Holocene.

Q. How much warmer will the Earth become for the present level of greenhouse gases?

A. That depends on how long we wait. The Charney climate sensitivity (3°C global warming for doubled CO_2) does not include slow feedbacks, principally disintegration of ice sheets and poleward movement of vegetation as the planet warms. When the long-lived greenhouse gases are changed arbitrarily, as humans are now doing, this change becomes the predominant forcing, and ice sheet and vegetation changes must be included as part of the response in determining long-term climate sensitivity.

It follows immediately from Figure 7 that equilibrium climate sensitivity when greenhouse gases are the forcing is 6°C for doubled CO_2, not 3°C (the temperature change in the figure is the temperature change in Antarctica, which is about twice the global mean temperature change). To achieve this full response we must wait until ice sheets have had time to melt and forests have had time to migrate. This may require hundreds of years, perhaps thousands of years. However, elsewhere (Hansen et al. 2007a) we have discussed evidence that forests are already moving and ice sheet albedos are already responding to global warming, so climate sensitivity is already partially affected by these processes.

Thus the relevant equilibrium climate sensitivity on the century time scale falls somewhere between 3°C and 6°C for doubled CO_2. The expected temperature change in the 21st century cannot be obtained by simply multiplying the forcing by the sensitivity, as we could in the paleoclimate case, because a century is not long enough to achieve the equilibrium response. Instead we must make computations with a model that includes the ocean thermal inertia, as is done in climate model simulations (IPCC 2007; Hansen et al. 2007b). However, these models do not include realistically all of the slow feedbacks, such as ice sheet and forest dynamics.

Q. The huge climate changes over the past few hundred thousand years show the dramatic effects accompanying global temperature change of only a few degrees.

And you infer climate sensitivity from the documented climate variations. Yet the climate changes and mechanisms are intricate, and it is difficult for the lay person to grasp the details of these analyses. Is there other evidence supporting the conclusion that burning of the fossil fuels will have dramatic effects upon life on Earth?

A. Yes. Climate fluctuations in the Pleistocene (past 1.8 million years) are intricate, as small forcings are amplified by feedbacks, including 'carbon cycle' feedbacks. Atmospheric CO_2 varies a lot because carbon is exchanged among its surface reservoirs: the atmosphere, ocean, soil, and biosphere. For example, the solubility of CO_2 in the ocean decreases as the ocean warms, a positive feedback causing much of the atmospheric CO_2 increase with global warming. That feedback is simple, but the full story of how weak forcings create large climate change is indeed complex.

A useful complement to Pleistocene climate fluctuations is provided by longer time scales with larger CO_2 changes. Larger CO_2 changes occur on long time scales because of transfer of carbon between the solid earth and the surface reservoirs. The large CO_2 changes on these long time scales allow the Earth orbital climate oscillations to be viewed as 'noise'. Thus long time scales help provide a broader overview of the effect of changing atmospheric composition on climate.

A difficulty with long time scales is that knowledge of atmospheric composition changes is not as good. Samples of ancient air preserved in ice cores exist for only about one million years. But there are indirect ways of measuring ancient CO_2 levels to better than a factor of two. Atmospheric composition and other climate forcings are known well enough for the combination of Pleistocene climate variations and longer-term climate change to provide an informative overview of climate sensitivity and a powerful way to assess the role of humans in altering global climate.

Q. What determines the amount of CO_2 in the air on long time scales?

On long (geologic) time scales two processes take CO_2 out of the surface reservoirs: (1) chemical weathering of silicate rocks, which results in the deposition of (calcium and magnesium) carbonates on the ocean floor, and (2) burial of organic matter, some of which eventually forms fossil fuels. Weathering is the more dominant process, accounting for ~80% of carbon removal from surface reservoirs (Berner 2004).

CO_2 is returned to the atmosphere principally via subduction of oceanic crustal plates beneath continents. When a continental plate overrides carbonate-rich ocean crust, the subducted ocean crust experiences high temperatures and pressures. Resulting metamorphism of the subducted crust into various rock types releases CO_2, which makes its way to the atmosphere via volcanic eruptions or related phenomena such as 'seltzer' spring water. This return of CO_2 to the atmosphere is called 'outgassing'.

Outgassing and burial of CO_2, via weathering and organic deposits, are not in general balanced at any given time (Edmond and Huh 2003). Depending on the movement of continental plates, the locations of carbonate-rich ocean crust, rates of mountain-building (orogeny), and other factors, at any given time there can be substantial imbalance between outgassing and burial. As a result, atmospheric CO_2 changes by large amounts on geologic time scales.

Q. How much do these geologic processes change atmospheric CO_2?

A. Rates of outgassing and burial of CO_2 are each typically 2-4 x 10**12 mol C/year (Staudigel et al. 1989; Edmond and Huh 2003). An imbalance between outgassing and burial of say 2 x 10**12 mol C/year, if confined entirely to the atmosphere, would correspond to ~0.01 ppm CO_2 per year. However, the atmosphere contains only of order 10**(-2), i.e., about 1%, of the total CO_2 in the surface carbon reservoirs (atmosphere, ocean, soil, biosphere), so the rate of geologic changes to atmospheric CO_2 is only about 0.0001 ppm CO_2 per year. This compares to the present human-made atmospheric CO_2

increase of ~2 ppm per year. Fossil fuels burned now by humans in one year contain the amount of carbon buried in organic sediments in approximately 100,000 years.

The contribution of geologic processes to atmospheric CO_2 change is negligible compared to measured human-made changes today. However, in one million years a geologic imbalance of 0.0001 ppm CO_2 per year yields a CO_2 change of 100 ppm. Thus geologic changes over tens of millions of years can include huge changes of atmospheric CO_2, of the order of 1000 ppm of CO_2. As a result, examination of climate changes on the time scale of tens of millions of years has the potential to yield a valuable perspective on how climate changes with atmospheric composition.

Q. What is the most useful geologic era to consider for that purpose?

A. The Cenozoic era, the past 65 million years, is particularly valuable for several reasons. First, we have the most complete and most accurate climate data for the most recent era. Second, climate changes in that era are large enough to include ice-free conditions. Third, we know that atmospheric greenhouse gases were the principal global forcing driving climate change in that era.

Q. How do you know that greenhouse climate forcing was dominant in the Cenozoic?

A. Climate forcings, perturbations of the planet's energy balance, must arise from either changes in the incoming energy, changes that alter the planetary surface, or changes within the atmosphere. Let us examine these three in turn.

Solar luminosity is growing on long time scales, at a rate such that the sun was ~0.5% dimmer than today in the early Cenozoic (Sackmann et al. 1993). Because the Earth absorbs about 240 W/m^2 of solar energy, the solar climate forcing at the beginning of the Cenozoic was about -1 W/m^2 relative to today. This small growth of solar forcing through the Cenozoic era, as we will see, is practically negligible.

Changing size and location of continents can be an important climate forcing, as the albedo of the Earth's surface depends on whether the surface is land or water and on the angle at which the sun's rays strike the surface. A quarter of a billion years ago the major continents were clumped together (Figure 9) in the super-continent Pangea centered on the equator (Keller and Pinter 1996). However, by the beginning of the Cenozoic (65 million years before present, 65 My BP, the same as the end of the Cretaceous) the continents were close to their present latitudes. The direct (radiative) climate forcing due to this continental drift is no more than ~ 1 W/m^2.

In contrast, atmospheric CO_2 reached levels of 1000-2000 ppm in the early Cenozoic (Pagani et al. 2005; Royer 2006), compared with values as low as ~180 ppm during recent ice ages. This range of CO_2 encompasses about three CO_2 doublings and thus a climate forcing more than 10 W/m^2. So it is clear that changing greenhouse gases provided the dominant global climate forcing through the Cenozoic era.

We are not neglecting the fact that dynamical changes of ocean and atmospheric currents can affect global mean climate (Rind and Chandler 1991). Climate variations in the Cenozoic are too large to be accounted for by such dynamical hypotheses.

Q. What caused atmospheric CO_2 amount to change?

A. At the beginning of the Cenozoic era, 65 My BP, India was just south of the Equator (Figure 9), but moving north rapidly, at about 15 cm/year. The Tethys Ocean, separating Eurasia from India and Africa, was closing rapidly. The Tethys Ocean had long been a depocenter for carbonate sediments. Thus prior to the collision of the Indian and African plates with the Eurasian plate, subduction of carbonate-rich oceanic crust caused outgassing to exceed weathering, and atmospheric CO_2 increased.

With the Indo-Asian collision at about 50 My BP. massive uplift of the Himalayas and the Tibetan Plateau began, and since then drawdown of atmospheric CO_2 by weathering has generally exceeded CO_2 outgassing (Raymo and Ruddiman 1992). Although less important, the Alps were formed in the same time frame, as the African continental plate pushed against Eurasia. With the closing of the Tethys Ocean, the major depocenters for carbonate sediments became the Indian and Atlantic oceans, because the major rivers of the world empty into those basins.

For the past 50 million years and continuing today, regions of subduction of carbonate rich ocean crust have been limited. Thus, while the oceans have been a strong sink for carbonate sediments, little carbonate is being subducted and returned to the atmosphere as CO_2 (Edmond and Huh 2003). As a result, over the past 50 million years there has been a long-term decline of greenhouse gases and global temperature.

Q. Can you illustrate this long-term cooling trend?

A. Yes, with certain caveats. Figure 10a shows a quantity, $\delta^{18}O$, that provides an indirect measure of global temperature over the Cenozoic era. $\delta^{18}O$ defines the amount of the heavy oxygen isotope ^{18}O found in the shells of microscopic animals (foramininfera) that lived in the ocean and were deposited in ocean sediments. By taking ocean cores of the sediments we can sample shells deposited over time far into the past. Figure 10a shows the average result from many ocean cores around the world obtained in deep sea drilling programs (Zachos et al 2001).

The proportion of $\delta^{18}O$ in the foraminifera shell depends on the ocean water temperature at the time the shell was formed, and thus $\delta^{18}O$ provides a proxy measure of temperature. However, an ice sheet forming on the Earth's surface has an excess of ^{16}O in its H_2O molecules, because ^{16}O evaporates from the ocean more readily than ^{18}O, leaving behind a relative excess of ^{18}O in the ocean. As long as the Earth was so warm that little ice existed on the planet, as was the case between 65 My BP and 35 My BP, ^{18}O

yields a direct measure of temperature, as indicated by the red curve and the temperature scale on the left side of Figure 10a.

The sharp change of $\delta^{18}O$ at about 34 My BP was due to rapid glaciation of the Antarctic continent (Lear et al. 2000; Zachos et al. 2001). From 34 My BP to the present, $\delta^{18}O$ changes reflect both ice volume and ocean temperature changes. We cannot separate the contributions of these two processes, but both increasing ice volume and decreasing temperature change $\delta^{18}O$ in the same sense, so the $\delta^{18}O$ curve continues to be a qualitative measure of changing global temperature, chronicling the continuing long-term cooling trend of the planet over the past 50 million years.

The black curve in Figure 10a shows the rapid glacial-interglacial temperature oscillations, which are smoothed out in the mean (red and blue) curves. Figure 10b expands the time scale for the most recent 3.5 million years, so that the glacial-interglacial fluctuations are clearer. Figure 10c further expands the most recent 425,000 years, showing the familiar Pleistocene ice ages punctuated by brief interglacial periods. Note that the period of civilization within the Holocene is invisibly brief with the resolution in Figure 10a. Homo sapiens have been present for about 200,000 years, and the predecessor species, homo erectus, for about 2 million years, still rather brief on the time scale of Figure 10a.

Q. Can you explain the nature of the global climate change illustrated in Figure 10?

A. The long-term cooling from 50 My BP to the present must be due primarily to decreasing greenhouse gases, primarily CO_2, which fell from 1000-2000 ppm 50 My BP to 180-280 ppm in recent glacial-interglacial periods. Full glaciation of Antarctica, at about 34 My BP (Lear et al. 2000; Zachos et al. 2001), occurred when CO_2 fell to 500 ±150 ppm (Hansen and Sato 2007).

Between 34 and 15 My BP global temperature fluctuated, with Antarctica losing most of its ice at about 27 My BP. Antarctica did not become fully glaciated again until about 15 My BP. Deglaciation of Antarctica was associated with increased atmospheric CO_2 (Pagani et al. 2005), perhaps due to the negative feedback caused by reduction of weathering (Lear et al. 2004) as ice and snow covered Antarctica as well as the higher reaches of the Himalayas and the Alps.

Cooling and ice growth resumed at about 15 My BP continuing up to the current Pleistocene ice age. During the past 15 My CO_2 was at a low level, about 200-400 ppm (Zachos et al. 2001; Pagani et al. 2005) and its proxy measures are too crude to determine whether it had a long-term trend. Thus it has been suggested that the cooling trend may have been due to a reduction of poleward ocean heat transports, perhaps caused by the closing of the Isthmus of Panama at about 12 My BP or the steady widening of the oceanic passageway between South America and Antarctica.

We suggest that continued global cooling trend after 15 My BP is probably due to continued drawdown of atmospheric CO_2 of a degree beneath the detection limit of proxy measures. Little additional drawdown is needed, because the increasing ice cover on the planet makes climate sensitivity extremely high, and the logarithmic nature of CO_2 forcing (see formulae in Hansen et al. 2000) makes a small CO_2 change very effective at low CO_2 amounts. Further, there are reasons to expect CO_2 drawdown in this period: the Andes were rising rapidly in this period (Garzione et al. 2006), at a rate of about 1 mm per year (1 km per My). The mass of the Andes increased so much as to slow down the convergence of the Nazca and South American plates by 30% in the past 3.2 My (Iaffaldano et al. 2007). Increased weathering and reduced subduction both contribute to drawdown of atmospheric CO_2. Finally, a strong indication that CO_2 has been declining over the relevant period is provided by the increase in the proportion of C4 plants relative to C3 plants that occurred between 8 and 5 My BP (Cerling et al. 1993); C4 plants are much more resilient to low atmospheric CO_2 levels.

In summary, there are many uncertainties about details of climate change during the Cenozoic era. Yet important conclusions emerge, as summarized in Figure 11. The dominant forcing that caused global cooling, from an ice free planet to the present world with large ice sheets on two continents, was a decrease in atmospheric CO_2. Human-made rates of change of climate forcings, including CO_2, now dwarf the natural rates.

Q. Is this relevant to the question of whether we need to "wrestle" with climate change?

A. Yes, it may help resolve the conundrum sensed by some lay persons based on realization that the natural world has undergone huge climate variations in the past. That is true, but those climate variations produced a different planet. If we follow "business as usual" greenhouse gas emissions, putting back into the air a large fraction of the carbon that was stored in the ground over millions of years, we surely will set in motion large climate changes with dramatic consequences for humans and other species.

Q. Why are climate fluctuations in the past few million years (Figure 10b) so regular?

A. The instigator is the distribution of sunlight on the Earth, which continuously changes by a small amount because of the gravitational pull of other planets, especially Jupiter and Saturn, because they are heavy, and Venus, because it comes close. The most important effect is on the tilt of the Earth's spin axis relative to the plane of the Earth's orbit (Figure 12). The tilt varies by about 2° with a regular periodicity of about 41 Ky (41,000 years). When the tilt is larger it exposes both polar regions to increased sunlight at 6-month intervals. The increased heating of the polar regions melts ice in both hemispheres.

The 41 Ky climate variability is apparent in Figure 10b and is present in almost all climate records. However, glacial-interglacial climate variations became more complex in the most recent 1.2 My, with large variations at ~100 Ky periodicity, as well as ~41 Ky and ~23 Ky periods. As the planet became steadily colder over the past several million years, the amplitude of glacial-interglacial climate swings increased (Figure 10b) as ice sheet area increased. Ice sheets on Northern Hemisphere continents, especially North America, extended as far south as 45N latitude. Similar ice sheets were not possible in the Southern Hemisphere, which lacked land at relevant latitudes.

Hemispheric asymmetry in ice sheet area allows two additional Earth orbital parameters, which work in concert, to come into play. Gravitational tugs of the planets cause the eccentricity of the Earth's orbit about the sun to vary from near zero (circular) to an eccentricity of about 0.06. When the orbit is significantly non-circular, this allows another orbital parameter, axial precession, to become important Precession, which determines the date in the year at which the Earth in its elliptical orbit is closest to the sun, varies with a periodicity of ca. 23 Ky. When the Earth is closest to the sun in Northern Hemisphere winter, thus furthest from the sun in summer, ice sheet growth in the Northern Hemisphere is encouraged by increased winter snowfall and cool summers. The effect of eccentricity + precession on ice sheet growth is opposite in the two hemispheres, so the effect is important only when the area of high albedo ice and snow is much different in the two hemispheres, as it has been in the past million years. Climate variations then include all three periodicities, ~23 Ky precession, ~41 Ky tilt, and ~100 Ky eccentricity, as has been demonstrated for the recent ice age cycles (Hays et al 1976).

Q. What are the current Earth orbital parameters?

A. Precession has the Earth closest to the sun in January, furthest in July, which would favor growth of Northern Hemisphere ice. But eccentricity is small, about 0.016, so the precession effect is not large. Tilt is about midway between its extremes headed toward smaller tilt, the next minimum tilt occurring in ~10 Ky. Smaller tilt favors ice sheet growth, so, if it were not for humans, we might expect a trend toward the next ice age.

But the trend may have been weak, because, by the time tilt reaches its minimum, the sun will be closest to the sun in Northern Hemisphere summer. Thus in this particular cycle the two mechanisms, tilt and eccentricity + precession, will be working against each other, rather than reinforcing each other. In any event, this natural tendency has become practically irrelevant in the age of fossil-fuel-burning humans.

Q. Why is the natural glacial-interglacial cycle irrelevant?

A. Earth orbital changes were only pacemakers for glacial-interglacial climate change, inducing changes of ice area and greenhouse gases. Changes of surface albedo and greenhouse gases were the mechanisms for climate change, providing the immediate causes of the climate changes. We showed in Figure 6 that these two mechanisms account for the glacial-interglacial climate variations.

Now humans are totally in control of these climate change mechanisms. Greenhouse gases are increasing far outside the range of natural glacial-interglacial variations (Figure 8) and ice is melting all over the planet. Humans are now in complete control of the mechanisms causing long-term climate change. The weak effect of slow orbital changes is overwhelmed by the far larger and faster human-made changes.

Humans are now entirely responsible for long-term climate change (see summary in Figure 13). However, in one sense it is misleading to say that humans are “in control”. Because of climate system inertia, positive feedback, and tipping points, there is a danger that humans could set in motion future changes that are practically impossible to control.

Q. Can we finally finish with this paleoclimate discussion?

A. Please allow one final comment. For the record, since I could only estimate broad ranges for CO_2 in the Cenozoic era, I should show at least one estimate from the proxy CO_2 data. Figure 14A shows estimated CO_2 for the entire Phanerozoic eon, the past 540 million years. I show this longer time interval, because it includes CO_2 changes so large as to make the errors in the proxies less in a relative sense.

Geologic evidence for ice ages and cool periods on this long time frame (Figure 14B) shows a strong correlation of climate with CO_2. Climate variations were huge, ranging from ice ages with ice sheets as far equatorward as 30 degrees latitude to a much warmer planet without ice. Although other factors were also involved in these climate changes, greenhouse gases were a major factor.

Q. Do you have any final comment for the court?

A. Yes. I would like to express my gratitude to the State of Iowa, which has always been so generous in providing educational opportunities to its people, even as many graduates go on to careers in other states across the nation. I was extremely fortunate to be able to attend the University of Iowa, and especially to learn in the Department of Physics and Astronomy of Prof. James Van Allen.

Q. Does this conclude your prepared Direct Testimony?

A. With the following References, Figures and captions, yes.

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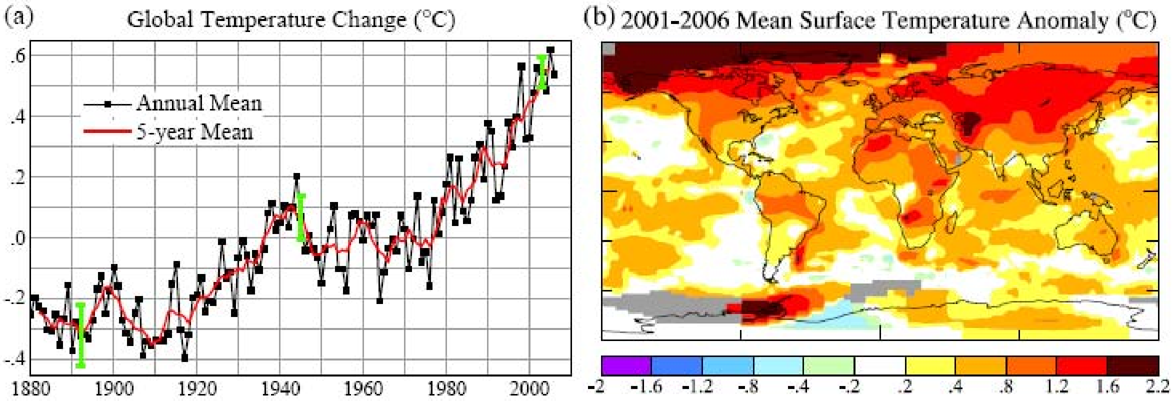


Figure 1. (a) Global surface temperature relative to 1951-1980 base period mean, based on surface air measurements at meteorological stations and ship and satellite SST (sea surface temperature) measurements, (b) temperature anomaly for first six years of the 21st century relative to 1951-1980 base period (update of figures of Hansen et al., *Proc. Natl. Acad. Sci.* **103**, 14288-14293, 2006). Green vertical bars in (a) are estimated 2σ error (95% confidence) of annual global mean temperature anomaly.

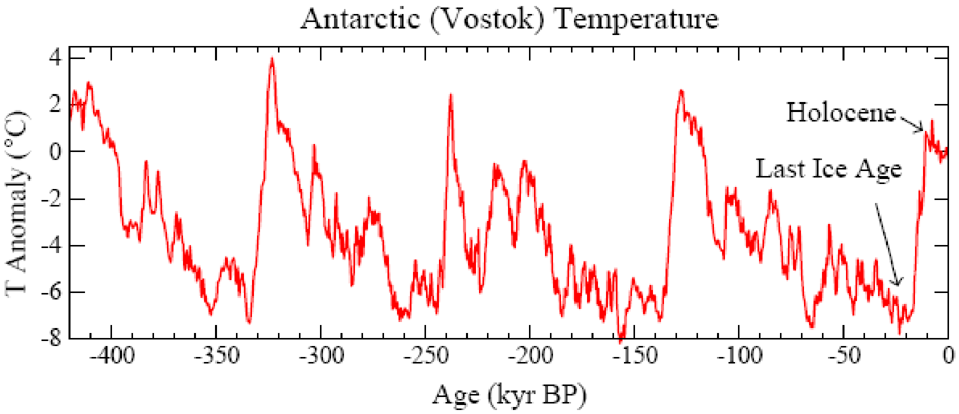


Figure 2. Temperature change in Antarctica over the past 420,000 as inferred from the isotopic composition of snow preserved in the ice sheet and extracted in the Vostok ice core (Vimeux et al., *Earth Planet. Sci. Lett.* **203**, 829-843, 2002).

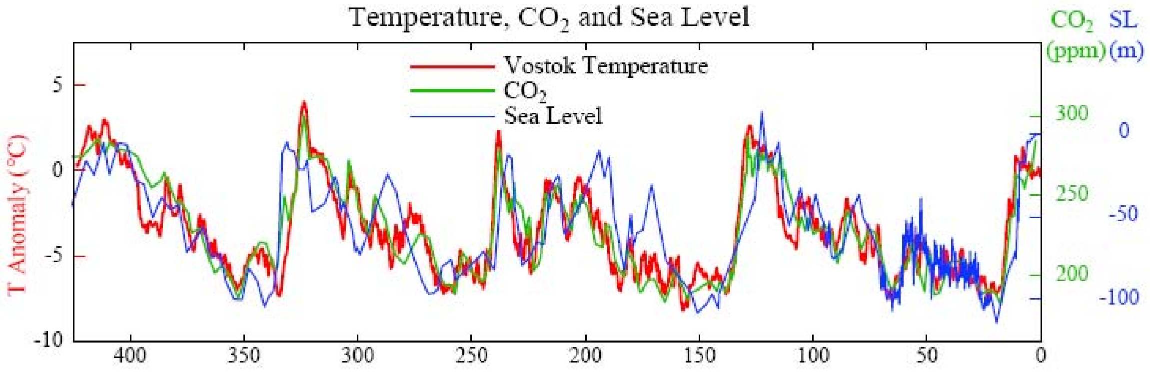


Figure 3. Temperature, CO$_2$, and sea level from Figure 3 of Hansen et al. (2007), where original data sources are provided.

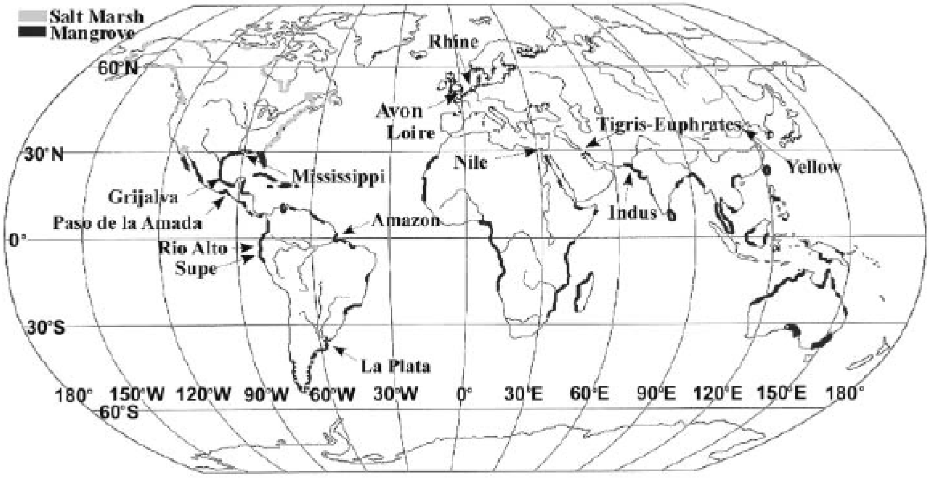


Figure 4. Distribution of early urban societies. Coastal mangroves and salt marshes shown by dark and light shades. (after Day, J.W. et al., *EOS Trans. AGU*, **88**, 169-170, 2007).

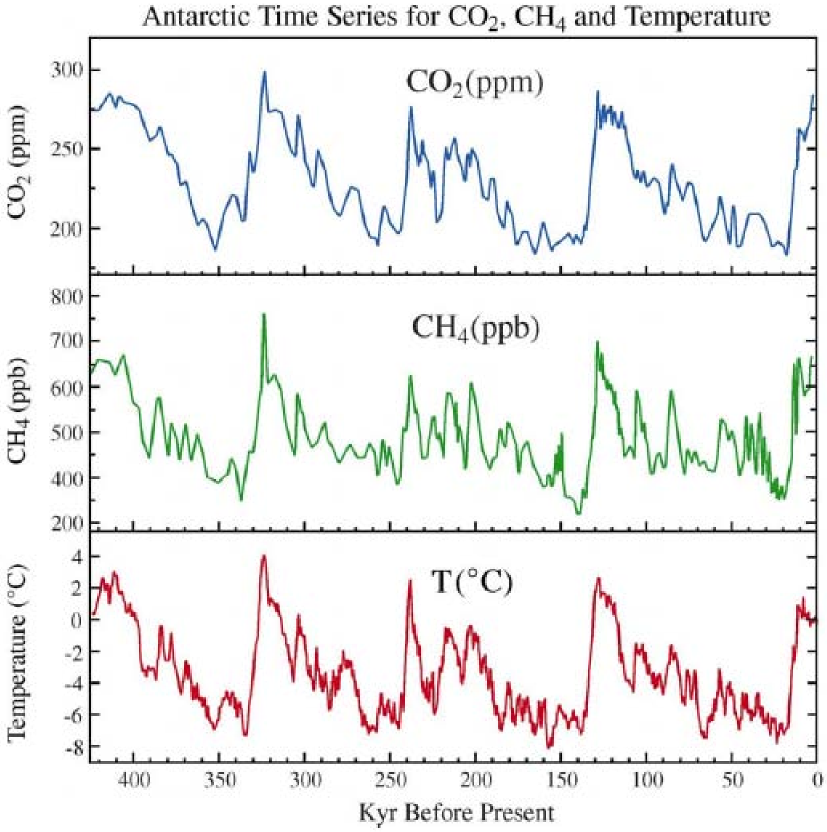


Figure 5. CO_2, CH_4, and temperature from the Vostok Antarctic ice core (Vimeux et al. 2002).

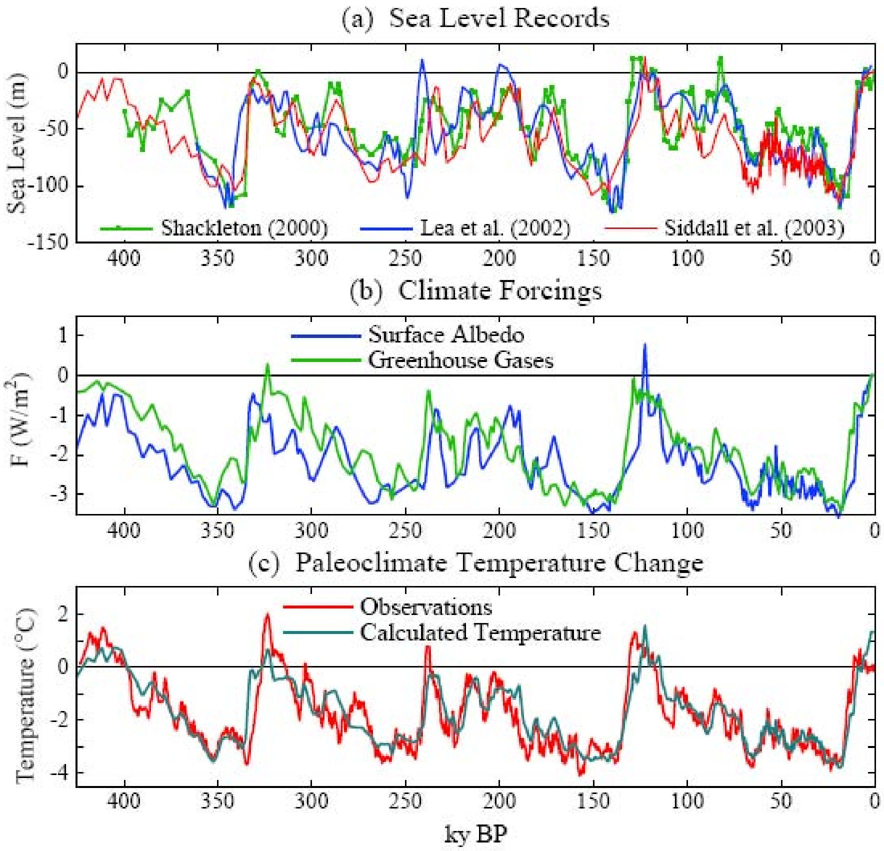


Figure 6. (a) sea level records from three sources, (b) climate forcings due to greenhouse gases (CO_2, CH_4 and N_2O) and surface albedo from the Siddall et al. sea level record, (c) calculated and observed paleo temperature change. Calculated temperature is the product of the forcing (b) and ¾°C per W/m^2. Observed temperature is the Vostok temperature (Figure 2) divided by two.

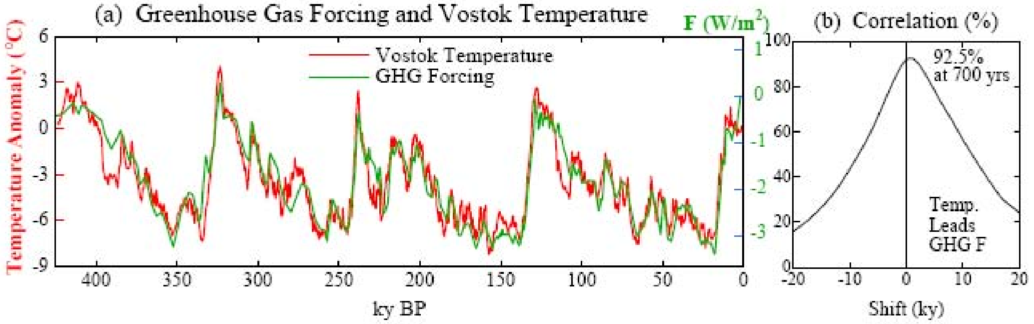


Figure 7. (a) Antarctic temperature from Vostok ice core (Vimeux et al. 2002) and global climate forcing (right scale) due to CO_2, CH_4 and N_2O. (b) Correlation (%) diagram showing lead of temperature over greenhouse forcing.

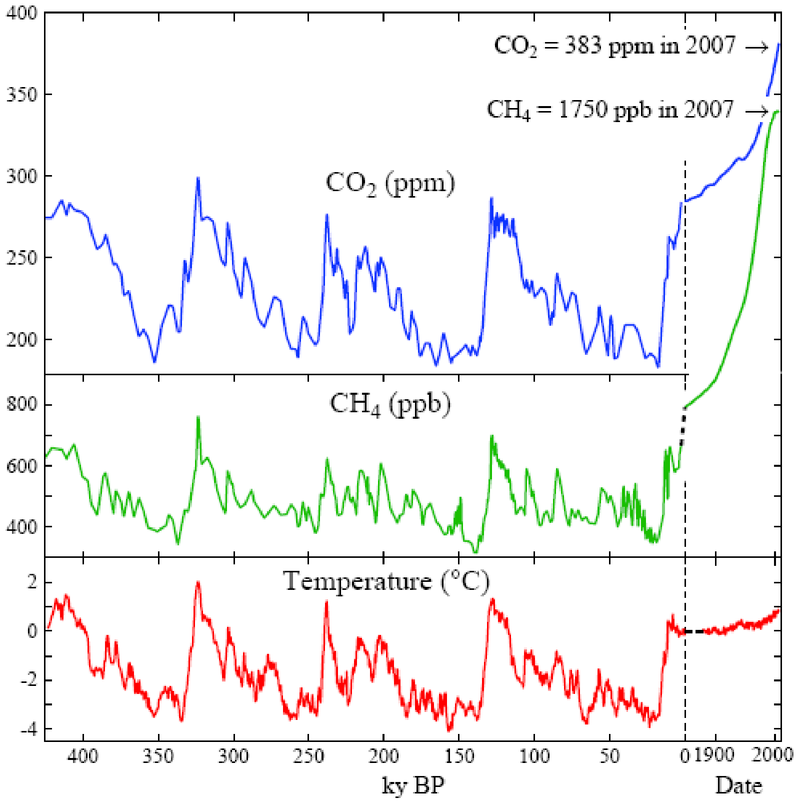
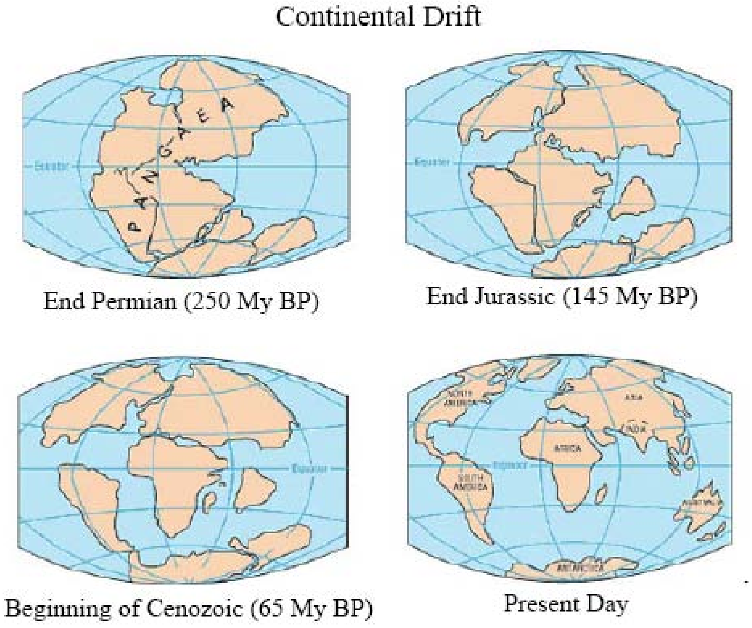


Figure 8. Extension of Antarctic CO_2, CH_4 and temperature records of Figure 5 into modern era. Antarctic temperature is divided by two to make it comparable to global temperature extension.



End Permian (250 My BP)

End Jurassic (145 My BP)

Beginning of Cenozoic (65 My BP)

Present Day

Figure 9. Continental positions at four times (adapted from Keller and Pinter 1996).

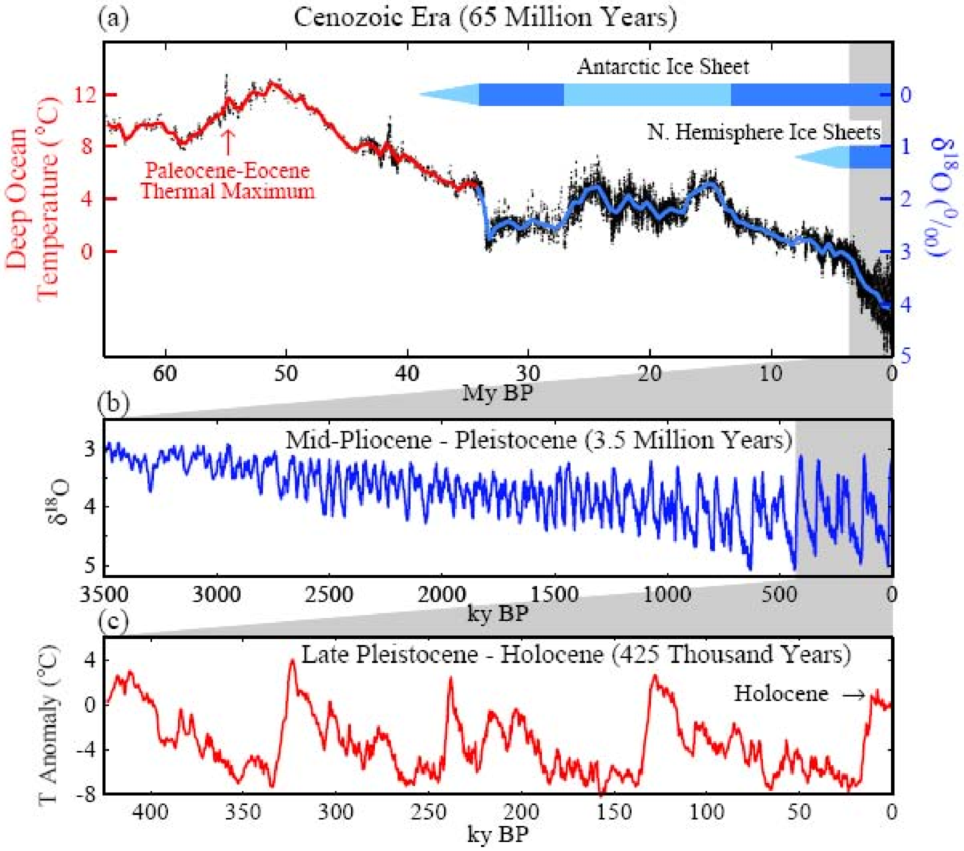
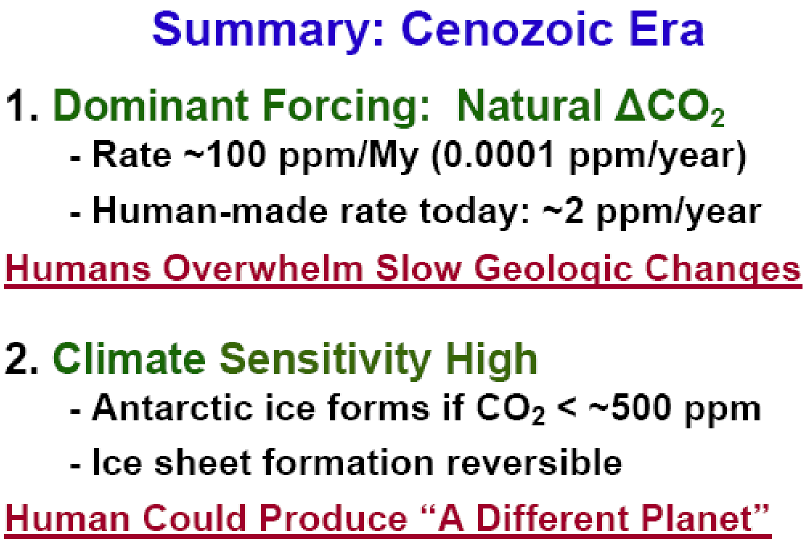


Figure 10. (a) Global compilation of deep-sea benthic foraminifera ^{18}O isotope records from Deep Sea Drilling Program and Ocean Drilling Program sites (Zachos et al 2001), temperatures applying only to ice-free conditions, thus to times earlier than ~35 My BP. The blue bar shows estimated times with ice present, dark blue being times when ice was equal or greater than at present. (b) Expansion of ^{18}O data for past 3.5 My. (Lisiecki and Raymo2005) (c) Temperature data based on Vostok ice core (Vimeux et al 2002).



Summary: Cenozoic Era

1. Dominant Forcing: Natural ΔCO_2

- Rate ~100 ppm/My (0.0001 ppm/year)
- Human-made rate today: ~2 ppm/year

Humans Overwhelm Slow Geologic Changes

2. Climate Sensitivity High

- Antarctic ice forms if CO_2 < ~500 ppm
- Ice sheet formation reversible

Human Could Produce "A Different Planet"

Figure 11. Principal inferences from Cenozoic Era relevant to present-day climate.

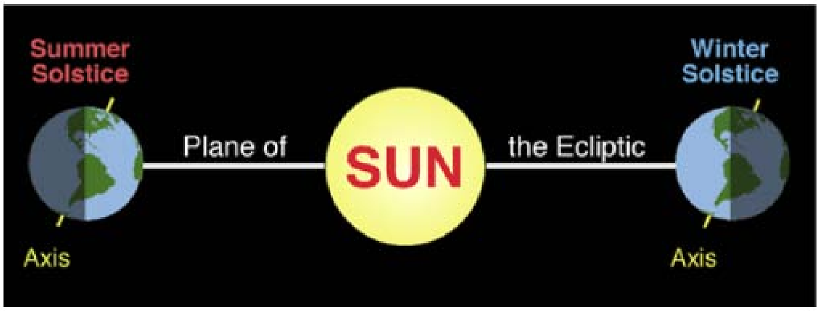
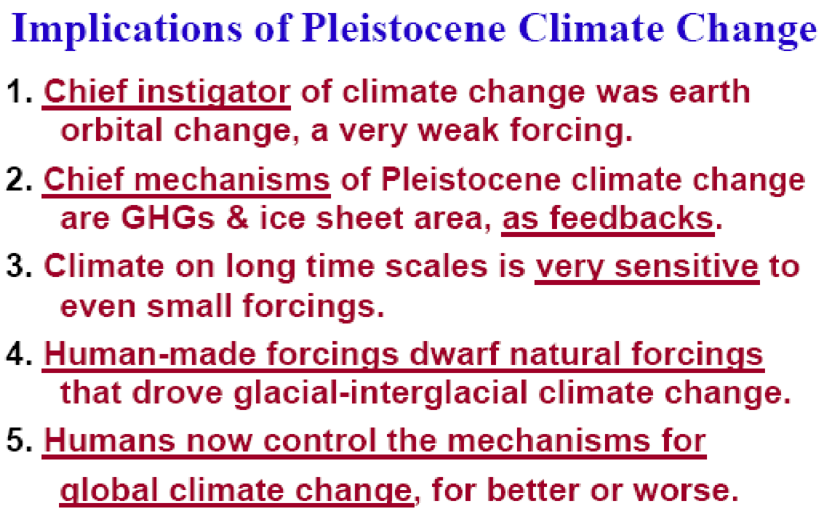


Figure 12. Increased tilt of Earth's spin axis exposes both poles to greater melt of high latitude ice.



Implications of Pleistocene Climate Change

1. Chief instigator of climate change was earth orbital change, a very weak forcing.
2. Chief mechanisms of Pleistocene climate change are GHGs & ice sheet area, as feedbacks.
3. Climate on long time scales is very sensitive to even small forcings.
4. Human-made forcings dwarf natural forcings that drove glacial-interglacial climate change.
5. Humans now control the mechanisms for global climate change, for better or worse.

Figure 13. Principal inferences from Pleistocene climate variations.

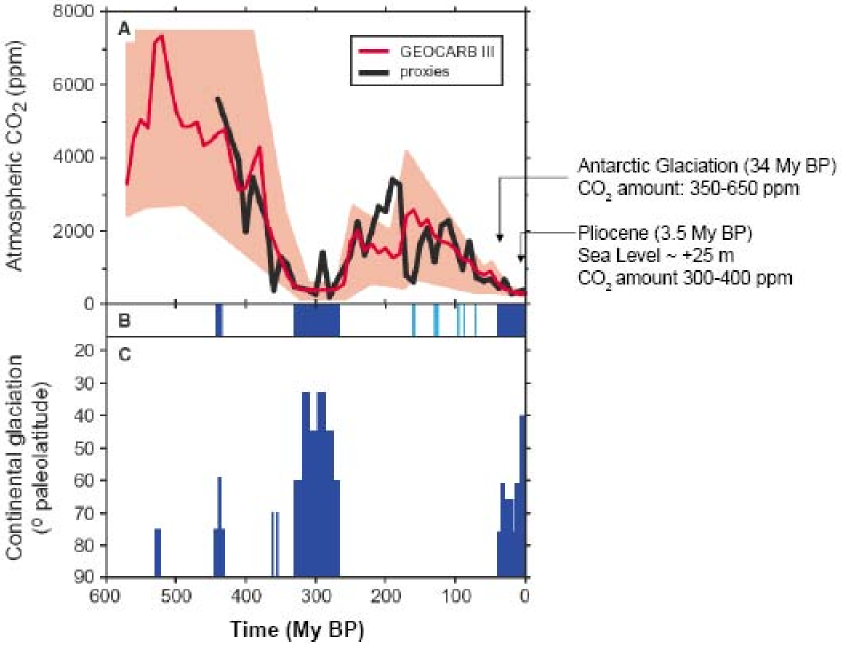


Figure 14. (A) Estimates of CO_2 in the Phanerozoic based on proxy CO_2 reconstructions and the GEOCARB-III model of Berner and Kothavala (2001), (B) Intervals of glacial (dark) or cool (light) climtes, (C) Latitudinal distribution of direct glacial records (tillites, striated bedrock, etc., from Crowley 1998). Figure is from Royer at al. (2004).

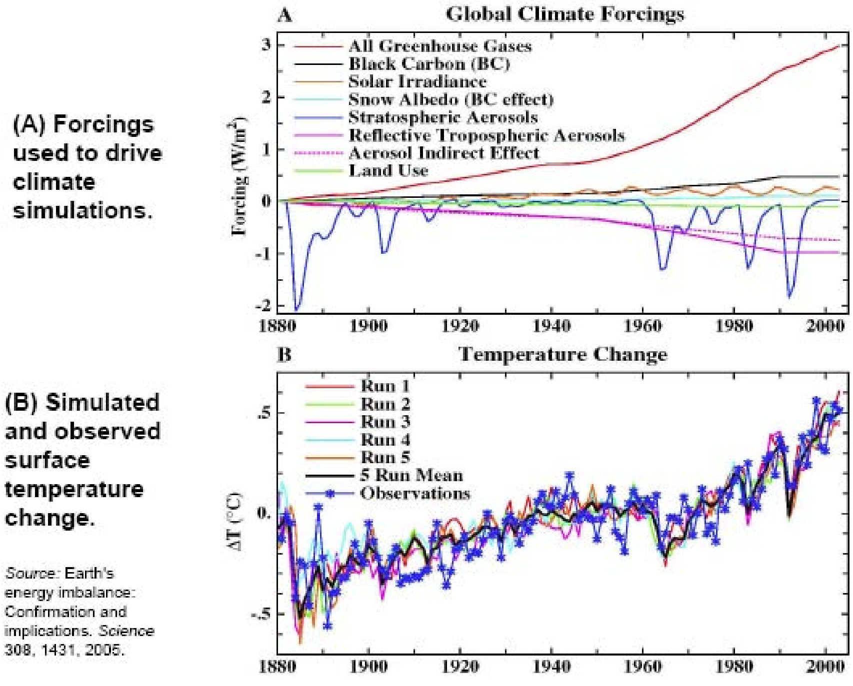
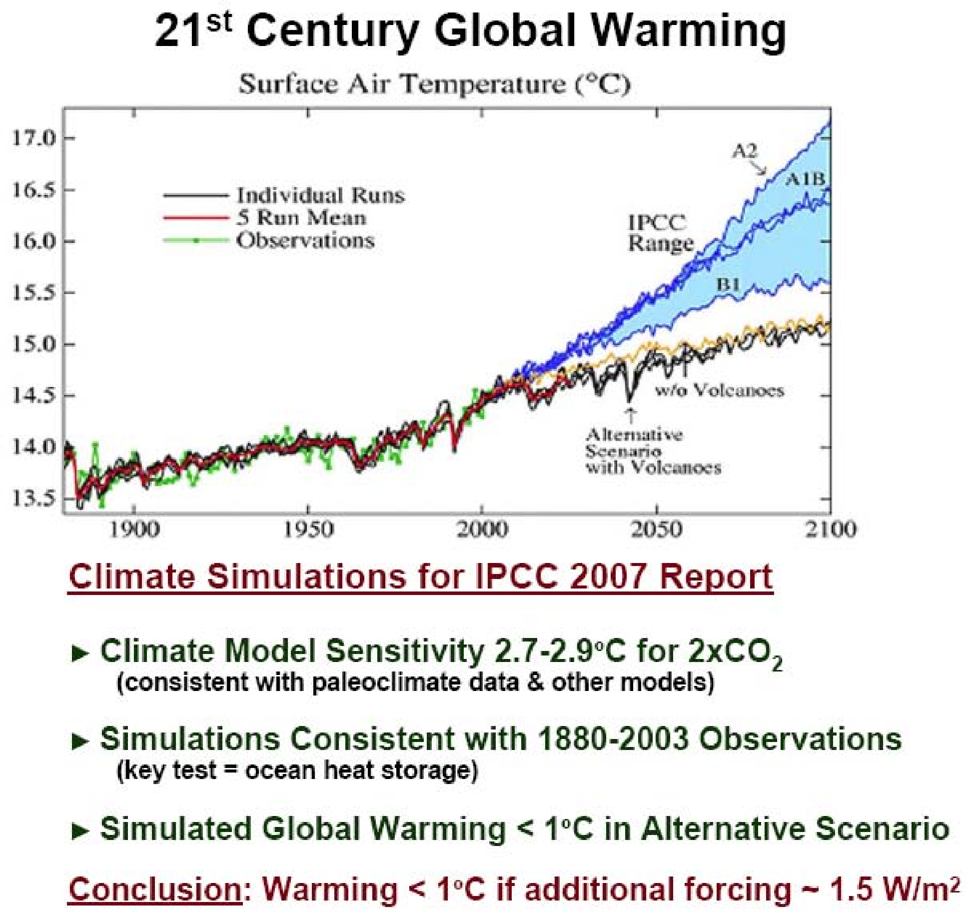


Figure 15. (A) Climate forcings since 1880, relative to the forcings in 1880. The largest forcing is the positive (warming) forcing due to greenhouse gases, but human-made aerosols and occasional volcanoes provide significant negative forcings. (B) Observed global temperature and temperature simulated with the GISS global climate model< which has climate sensitivity 2.8°C for doubled CO_2, using the forcings in (A).



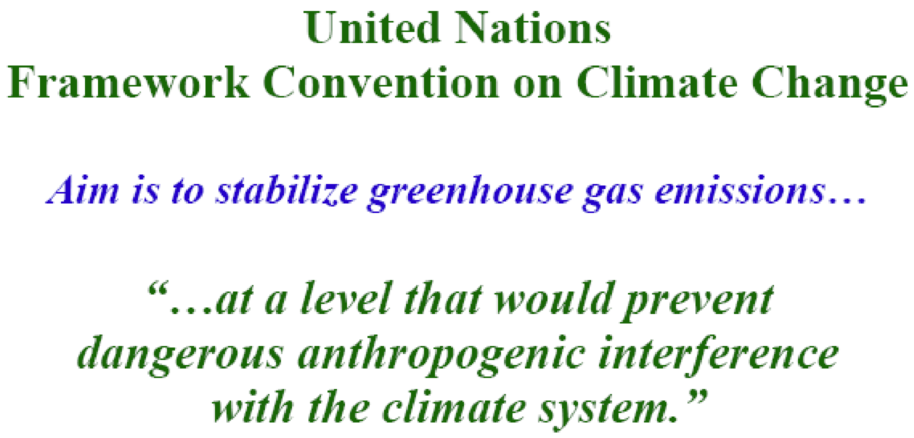
21^{st} Century Global Warming

Climate Simulations for IPCC 2007 Report

- ▶ Climate Model Sensitivity 2.7-2.9°C for $2xCO_2$
  (consistent with paleoclimate data & other models)
- ▶ Simulations Consistent with 1880-2003 Observations
  (key test = ocean heat storage)
- ▶ Simulated Global Warming < 1°C in Alternative Scenario

Conclusion: Warming < 1°C if additional forcing ~ 1.5 W/m^2

Figure 16. Extension of climate simulations through the 21st century. A1B (dark blue line) is a typical "business-as-usual" scenario for future greenhouse gas amounts. The "alternative scenario" has CO_2 peaking near 450 ppm, thus keeping additional warming beyond that in 2000 less than 1°C.



United Nations
Framework Convention on Climate Change

Aim is to stabilize greenhouse gas emissions…

"…at a level that would prevent
dangerous anthropogenic interference
with the climate system."

Figure 17. Practically all nations in the world, including the United States, have signed the Framework Convention on Climate Change. The problem is that "dangerous anthropogenic interference" in not defined.

Metrics for "Dangerous" Change

Ice Sheet Disintegration: Global Sea Level

1. Long-Term Change from Paleoclimate Data
2. Ice Sheet Response Time

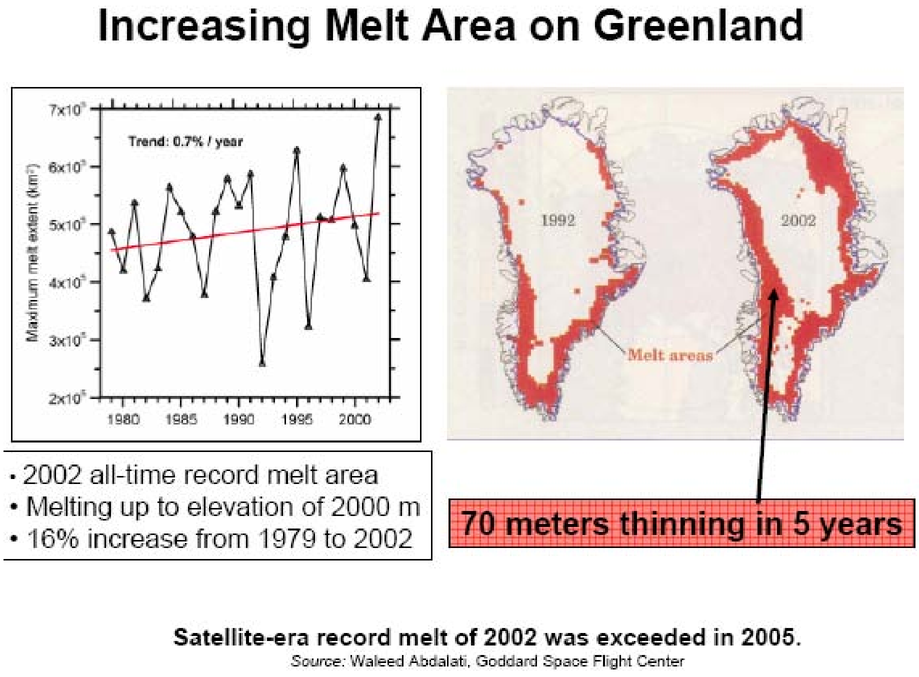
Extermination of Animal & Plant Species

1. Extinction of Polar and Alpine Species
2. Unsustainable Migration Rates

Regional Climate Disruptions

1. Increase of Extreme Events
2. Shifting Zones/Freshwater Shortages

Figure 18. Suggested principal metrics for defining the "dangerous" level of climate change.



Increasing Melt Area on Greenland

- 2002 all-time record melt area
- Melting up to elevation of 2000 m
- 16% increase from 1979 to 2002

70 meters thinning in 5 years

Satellite-era record melt of 2002 was exceeded in 2005.

Source: Waleed Abdalati, Goddard Space Flight Center

Figure 19. Area on Greenland with summer surface melt fluctuates from year to year, but has been increasing during the period of satellite observations. Recent years, not shown, have broken the record set in 2002.

Surface Melt on Greenland

Melt descending into a moulin, a vertical shaft carrying water to ice sheet base.

Source: Roger Braithwaite, University of Manchester (UK)

Figure 20. Summer surface melt-water on Greenland, which burrows a hole in the ice sheet, more than a mile thick, carrying water to the base of the ice sheet, where it serves as lubrication between the ice sheet and the ground beneath the ice sheet.

Jakobshavn Ice Stream in Greenland

Discharge from major Greenland ice streams is accelerating markedly.

Source: Prof. Konrad Steffen, Univ. of Colorado

Figure 21. The rate of discharge of giant icebergs from Greenland has doubled in the past decade.

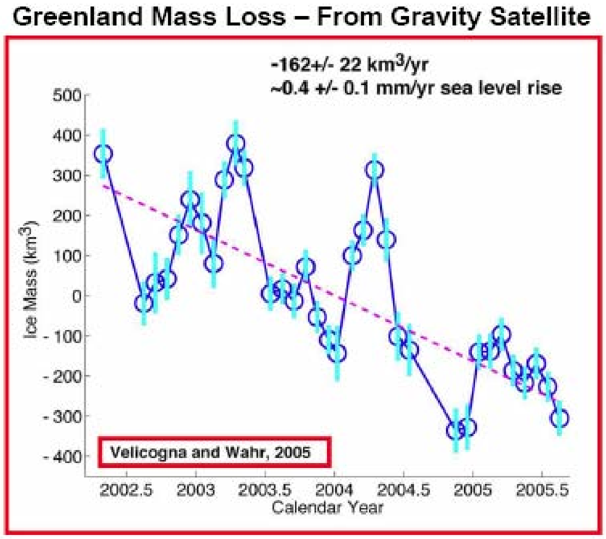


Figure 22. The GRACE satellite mission measures the Earth's gravitational field with such high precision that changes of the mass of the Greenland and Antarctic ice sheets can be measured. The ice sheet mass grows with winter snowfall and decreases during the melt season. Overall Greenland and West Antarctica are each now losing mass at rates of the order of 150 cubic kilometers of ice per year.

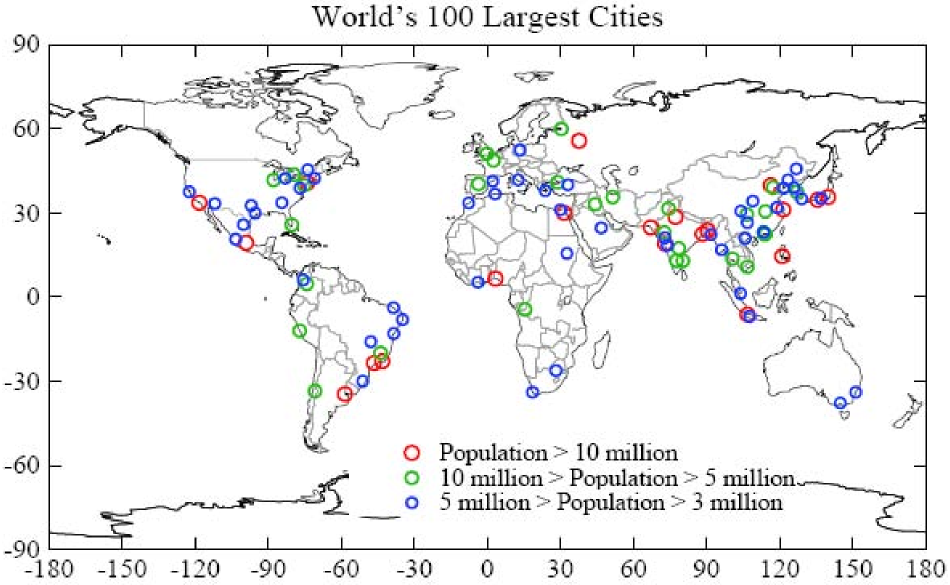
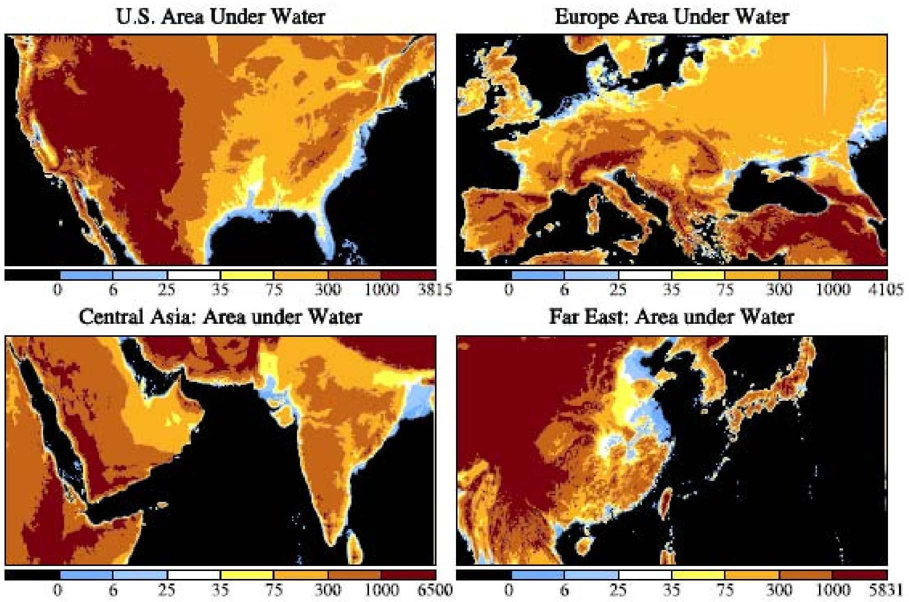


Figure 23. A majority of the world's 100 largest cities are located on coast lines.



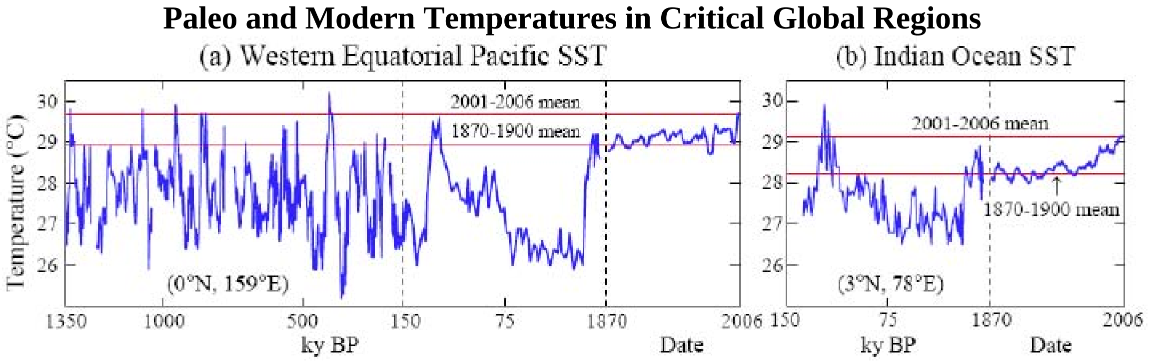
U.S. Area Under Water

Europe Area Under Water

Central Asia: Area under Water

Far East: Area under Water

Figure 24. A sea level rise of 25 meters would displace about 1 billion people. Even a 6 meter sea level rise would affect a few hundred million people, more than 1000 greater than the number in New Orleans affected by the Katrina hurricane disaster.



Paleo and Modern Temperatures in Critical Global Regions

(a) Western Equatorial Pacific SST

(b) Indian Ocean SST

Figure 25. Temperatures in the Pacific Warm Pool (a) and Indian Ocean (b), regions of special significance for global climate. Warm Pool temperature affects the transport of heat to much of the world via ocean and atmosphere; the Indian Ocean has the highest correlation with global mean temperature. In both regions warming of recent decades has brought the temperature within less than 1°C of the temperature during the warmest interglacial periods.

Arctic Change:

Future loss of Arctic sea ice could result in a loss of 2/3 of the world's polar bears within 50 years.

Source: U.S. Geological Survey
www.usgs.gov/newsroom/special/polar%5Fbears/

Images:
Sea Ice: Claire Parkinson & Robert Taylor
Polar Bears: Unknown

Figure 26. Unchecked global warming will, in effect, push polar species off the planet.

Mt. Graham Red Squirrel

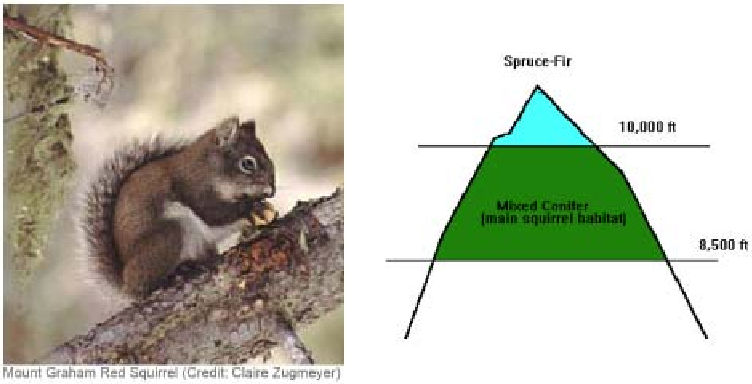
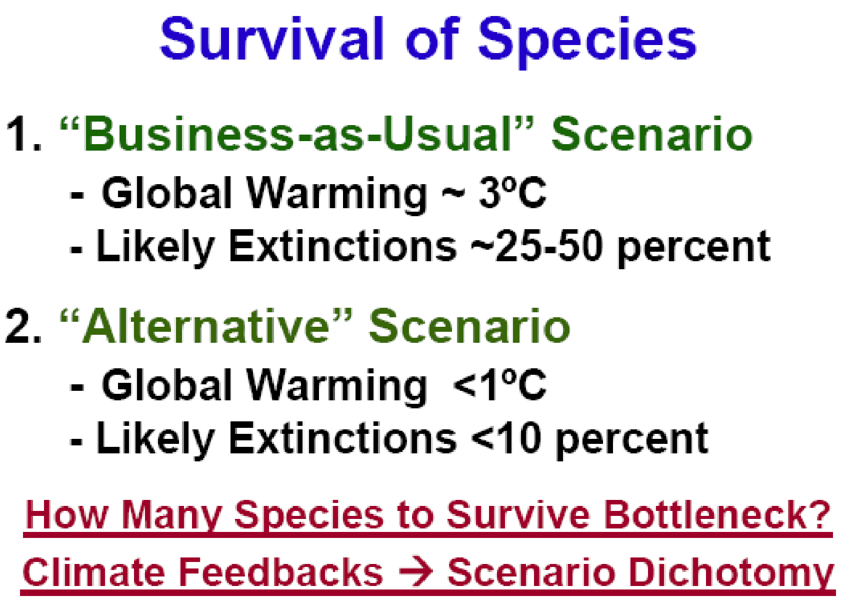

Mount Graham Red Squirrel (Credit: Claire Zugmeyer)

Figure 27. Alpine species can also be pushed to extinction as global warming causes isotherms to move up the mountains. The Mt. Graham red squirrel is an example of a threatened species. Impacts of climate change occur in bursts; forest fires in the lower reaches of the forested region cause permanent change, as the forests are unable to recover.



Survival of Species

1. **"Business-as-Usual" Scenario**
   - Global Warming ~ 3°C
   - Likely Extinctions ~25-50 percent

2. **"Alternative" Scenario**
   - Global Warming <1°C
   - Likely Extinctions <10 percent

How Many Species to Survive Bottleneck?

Climate Feedbacks → Scenario Dichotomy

Figure 28. The millions of species on the planet are being stressed in several ways, as humans have taken over much of the planet. Based on prior global warmings in the Earth's history, much slower than the present human-induced climate change, it is expected that the added stress from the large global climate change under business-as-usual scenarios would lead to eventual extinction of at least several tens of percent of extant species.

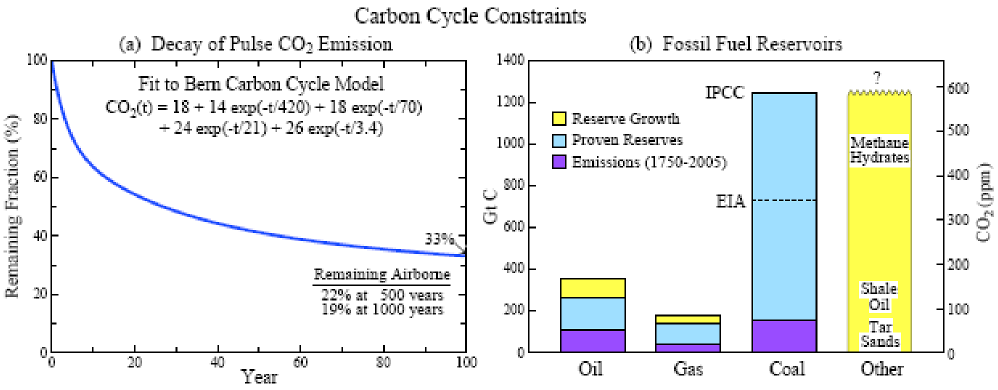
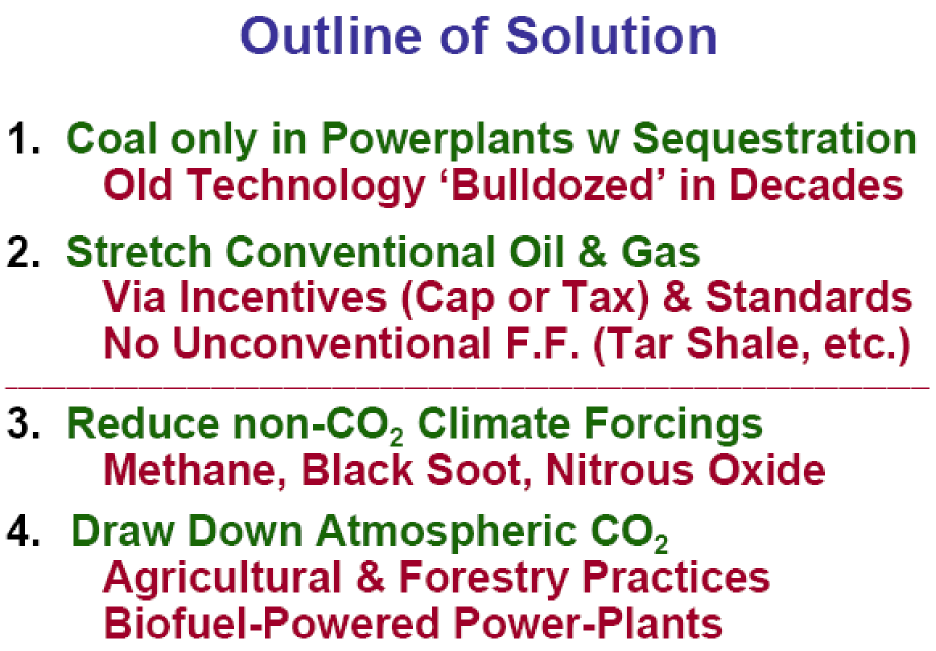


Figure 29. Critical carbon cycle facts. (a) A pulse of CO_2 added to the atmosphere by burning fossil fuels decays rapidly at first, with about half of the CO_2 taken up by sinks, principally the ocean, within the first quarter century. However, uptake slows as the CO_2 added to the ocean exerts a back-pressure on the atmosphere. Even after 1000 years almost one-fifth of the increase due to the initial pulse is still in the atmosphere. (b) Fossil fuel reservoirs are finite. Oil and gas proven and estimated reserves are sufficient to take atmospheric CO_2 to the neighborhood of 450 ppm. Coal and unconventional fossil fuels, if exploited without carbon capture, have the potential to at least double or triple the pre-industrial atmospheric CO_2 amount of 280 ppm.



Outline of Solution

1. Coal only in Powerplants w Sequestration
   Old Technology 'Bulldozed' in Decades
2. Stretch Conventional Oil & Gas
   Via Incentives (Cap or Tax) & Standards
   No Unconventional F.F. (Tar Shale, etc.)

---

3. Reduce non-CO_2 Climate Forcings
   Methane, Black Soot, Nitrous Oxide
4. Draw Down Atmospheric CO_2
   Agricultural & Forestry Practices
   Biofuel-Powered Power-Plants

Figure 30. CO_2 can be kept below 450 ppm only if coal and unconventional fossil fuels are used only where the CO_2 is captured and sequestered. If, there is a near-term moratorium in developed countries on new coal-fired power plants that do not sequester CO_2, a similar moratorium 10 years later in developing countries, and if over the period 2025-2050, existing coal-fired power plants are phased out linearly, CO_2 can be kept below 450 ppm. It will also be necessary to stretch conventional oil and gas supplies via economic incentives (a price on carbon emissions) that drive technology development needed for improved energy efficiency and renewable energies. A moderate gradually rising price on emissions can be achieved in a variety of means including individual emission allowances, cap-and-trade or taxes, but for maximum effectiveness it must be accompanied by standards, for example on building and vehicle efficiencies, and barriers to efficiency should be removed, e.g., by decoupling utility profits from the amount of energy sold. Important supplementary actions that will help stabilize climate sooner are reduction on non-CO_2 climate forcings and actions that draw down atmospheric CO_2, especially improve agricultural practices that sequester carbon in the soil, better preservation of forests, and perhaps power plants that burn biofuels and capture and sequester the CO_2.

Is Alternative Scenario Feasible?

Example: Phase-Out of 'Dirty' Coal

- CO_2 Sequestered at New Coal Power Plants after 2012/2022 in Developed/Developing Countries
- Coal Power Plants w/o Sequestration Bull-Dozed During 2025-2050 (Decision required by ~2020)
- Analogous to Montreal Protocol: Extra Time & Technology Assistance for Developing Countries
- Incentives for Developing Countries: Clean Air & Water, avoidance of Climate Catastrophes

Figure 31. The most difficult aspect of the alternative scenario is stabilization of CO_2 at a level of, at most, about 450 ppm. Given that it is impractical to capture CO_2 produced by mobile and other small sources burning oil or gas, and given the magnitude of potential emissions from coal, it is apparent that the one practical way to limit atmospheric CO_2 is to limit future coal use to places where CO_2 is captured and sequestered.

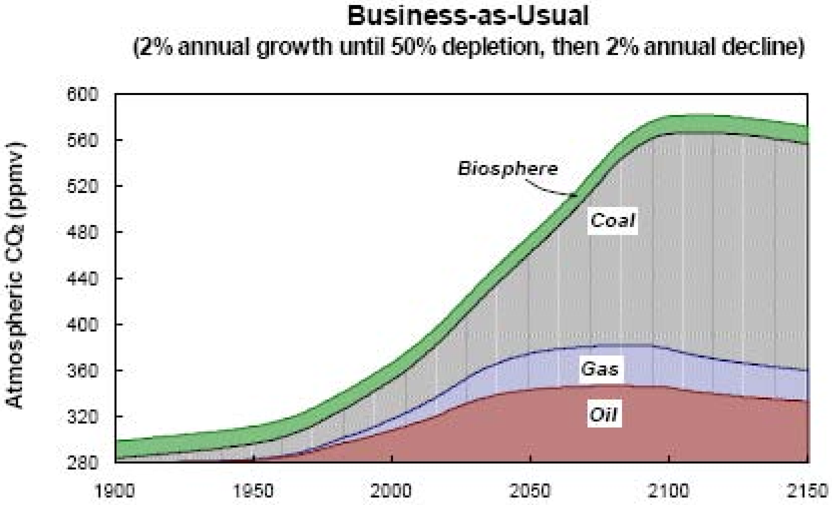


Figure 32. Business-as-usual use of all three conventional fossil fuels yields a doubling of pre-industrial CO_2 levels. This estimate does not include unconventional fossil fuel use or potential positive biosphere feedbacks that might accompany large climate response to doubled CO_2.

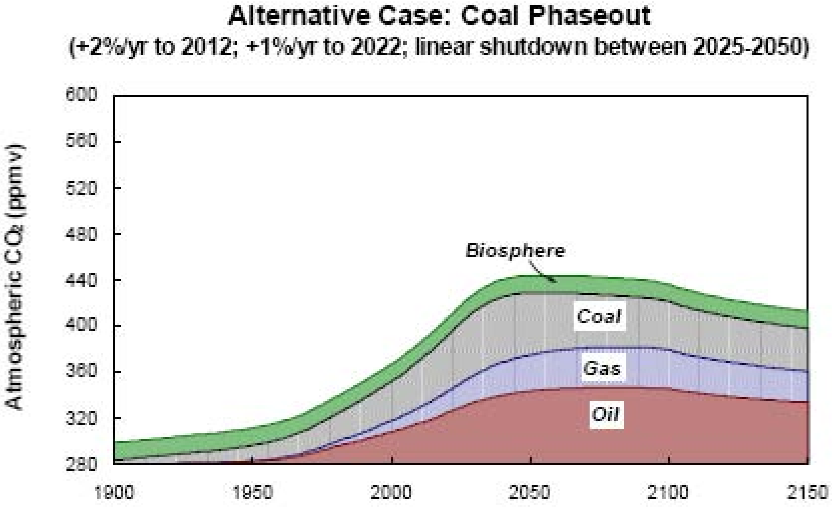
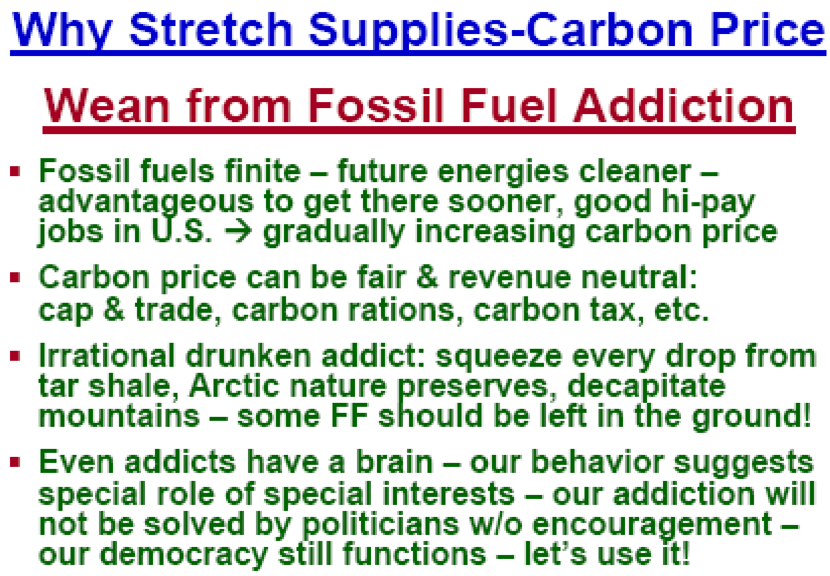


Figure 33. Phase-out of coal use, except where CO_2 is captured and equestered, yields maximum CO_2 under 450 ppm, even with oil and gas reserves used entirely, including anticipated oil and gas discoveries.



Why Stretch Supplies-Carbon Price

Wean from Fossil Fuel Addiction

- Fossil fuels finite – future energies cleaner – advantageous to get there sooner, good hi-pay jobs in U.S. → gradually increasing carbon price
- Carbon price can be fair & revenue neutral: cap & trade, carbon rations, carbon tax, etc.
- Irrational drunken addict: squeeze every drop from tar shale, Arctic nature preserves, decapitate mountains – some FF should be left in the ground!
- Even addicts have a brain – our behavior suggests special role of special interests – our addiction will not be solved by politicians w/o encouragement – our democracy still functions – let's use it!

Figure 34. Stretching of conventional fossil fuel supplies is essential to prevent irrational behavior of a drunken addict. The future beyond fossil fuel addiction is an attractive world, provided we do not damage the Earth irreparably in the transition. The only way to do that successfully is to wean ourselves off fossil fuels now, before we pass the climate tipping points. Environmental destruction, for the sake of squeezing every drop of black stuff from the Earth does not make sense.

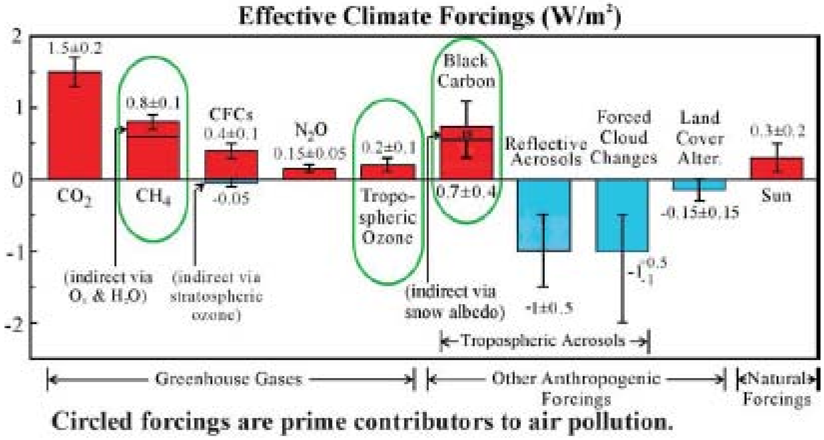


Figure 35. Reduction of non-CO_2 forcings is feasible. There is approximately enough potential for reduction of methane, tropospheric ozone, CFCs and black soot to restore planetary energy balance, the present imbalance being in the range 0.5-1 W/m^2. There would be large side benefits in reduction of these air pollutants, which are damaging to human health and agricultural productivity, especially in the developing world.

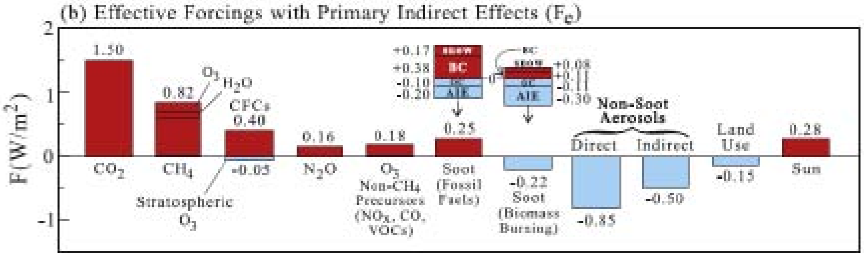


Figure 36. In evaluating the potential to reduce non-CO_2 forcings to mitigate climate change, it is important to include the 'efficacy' of each forcing (Hansen et al. 2005). Thus, for example, although the efficacy is low for black soot on global average, limitations on soot emissions in the Arctic would be very effective, suggesting the importance of placing constraints on ships and other sources within the Arctic.

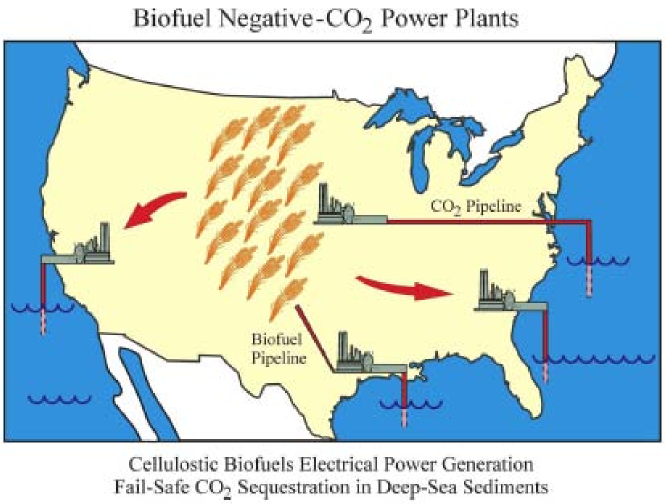
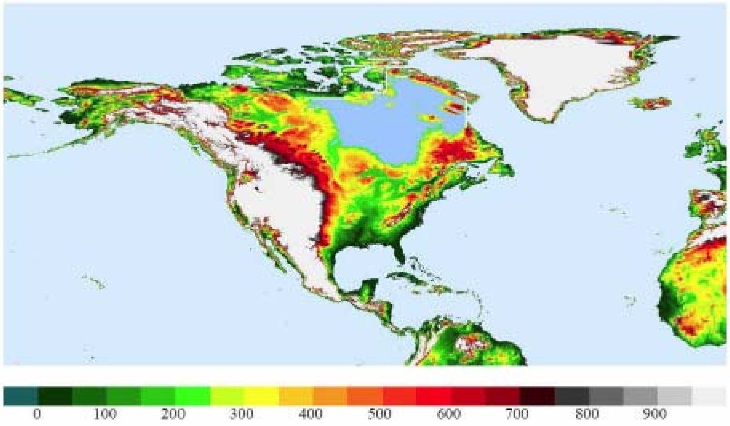


Figure 37. Power plants that burn biofuels could be used to draw down atmospheric CO_2, with the CO_2 sequestered locally in appropriate geologic formations or piped to the coast where it could be injected beneath ocean sediments where it is inherently stable. The biofuels should be natural grasses or other cellulosic fibers farmed in a way that promotes soil conservation and carbon storage in the soil, e.g., using no till practices.

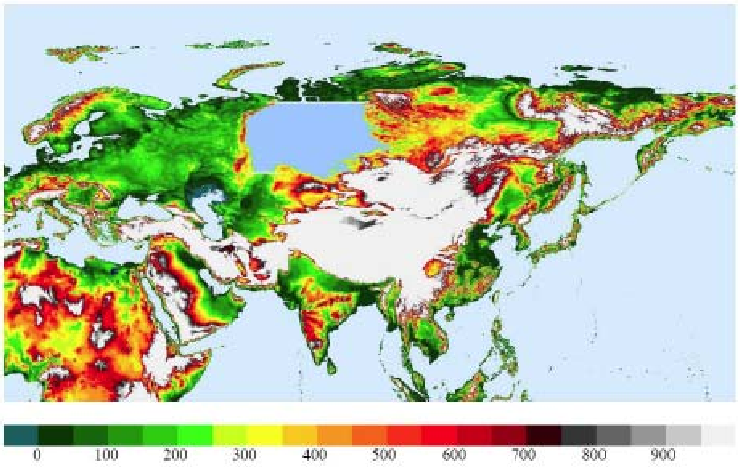
Lake Wobegone



Lake from indicated 200-meter high dams holds 1 meter sea level

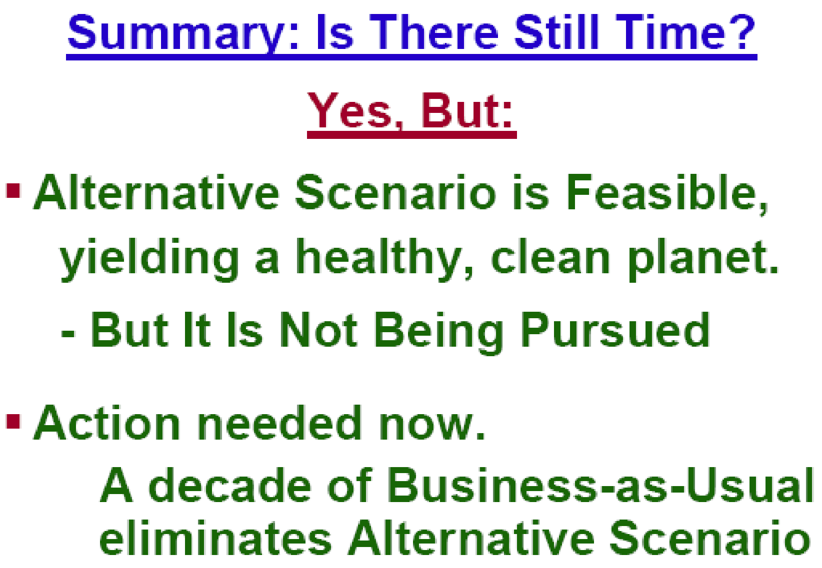
Figure 38. The water contributing one meter of sea level rise could be stored in a lake formed by placing 200 meter high dams at the indicated locations in Canada. This lake would cover a substantial area that is presently inhabited, providing an example of how difficult it would be to adapt to substantial disintegration of ice sheets.

Lake Wobegone II



Lake from indicated 242-meter high dams holds 1 meter sea level

Figure 39. The water contributing one meter of sea level rise could be stored in a lake formed by placing a 242 meter high dam at the indicated location in Russia. This lake would cover a substantial area that is presently inhabited, providing an example of how difficult it would be to adapt to substantial disintegration of ice sheets.

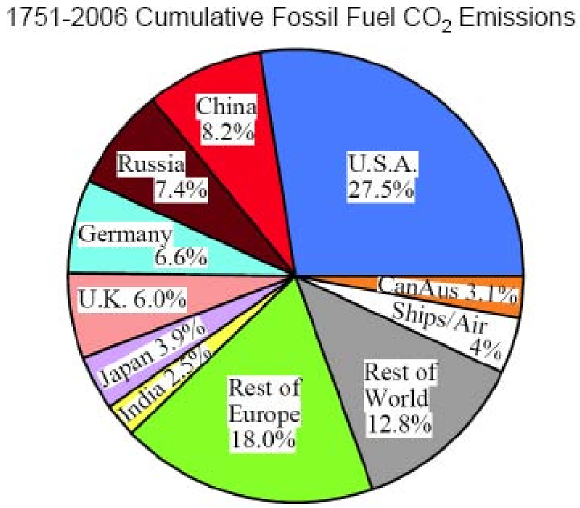


Summary: Is There Still Time?

Yes, But:

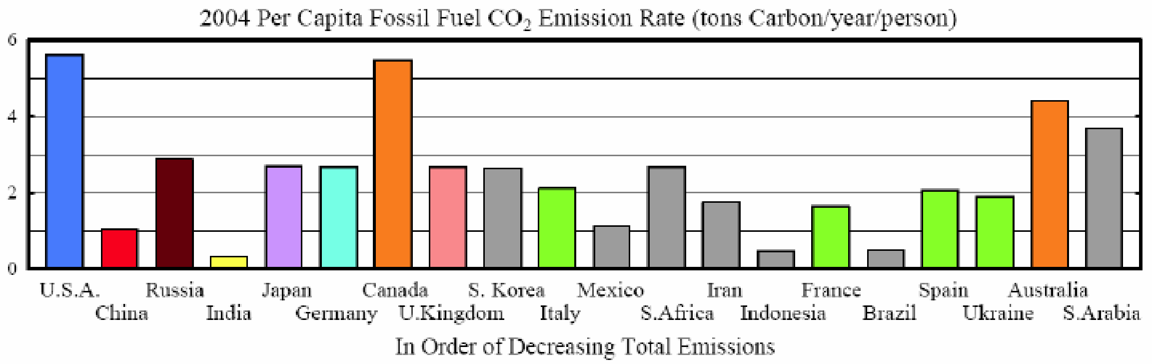
- Alternative Scenario is Feasible, yielding a healthy, clean planet.
  - But It Is Not Being Pursued
- Action needed now.
  A decade of Business-as-Usual eliminates Alternative Scenario

Figure 40. It is still feasible to keep atmospheric CO_2 well below 450 ppm and to keep additional global warming well below 1°C, but only if actions are taken quickly to get onto a new pathway. Business-as-usual growth of emissions, for even another decade, eliminates that possibility: atmospheric CO_2 will reach 400 ppm by 2015, and with a further 20% increase of CO_2-producing infrastructure, it becomes infeasible to avoid dangerous climate change. The principal action required to achieve the alternative scenario is a moratorium on new coal-fired power plants without sequestration in the West, followed by a similar moratorium in developing counties within a decade.



Update of Figure 10(e) of "Dangerous human-made interference with climate"

Figure 41. Responsibility for current climate change is proportional to cumulative emissions of long-lived greenhouse gases, not current emissions (Hansen et al. 2007b). Thus the United States has a responsibility more than a factor of three greater than any other country, and will continue to be most responsible for decades even though China is passing the United States in current emissions. Europw is responsible for more than 30% and the U.S. plus Canada and Australia are responsible for another 30%.



Update of Figure 10(g) of "Dangerous human-made interference with climate"

Figure 42. Per capita CO_2 emissions, with countries ranked in order of total emissions.

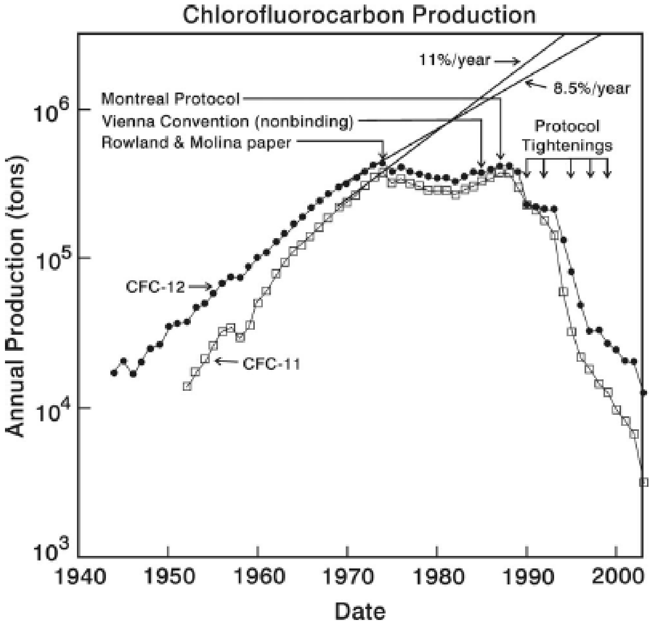


Figure 43. Production of CFCs stabilized (no new factories) immediately after the first warning that the may affect stratospheric ozone. Production began to increase in the 1980s for refrigeration in developing countries, but after the Montreal Protocol and its subsequent tightenings production fell rapidly. Developing countries were allowed 10 years longer than developed countries to phase out CFC use and technical assistance with alternative chemicals was provided by developed countries through the World Bank.

Ozone Success Story

↑1. **Scientists**: Clear warning

↑2. **Media**: Transmitted the message well

3. **Special Interests**: Initial oposition, but forsook disinformation, pursued advanced technologies

↑↑4. **Public**: quick response; spray cans replaced; no additional CFC infrastructure built

↑5. **Government**: U.S./Europe leadership; allow delay & technical assistance for developing countries

Figure 44. All parties deserve credit for the success in avoiding ozone catastrophe. Scientists provided a clear message, the media reported it, the public was responsive by reducing frivolous uses of CFC for spray cans, and governments, led by the United States took leadership roles in defining solutions. Special interests, specifically Dupont Chemical company, initially disputed the science, but eventually focused upon substitute chemicals.

Global Warming Story

↓1. **Scientists**: Fail to make clear distinction between climate change & BAU = A Different Planet

↓2. **Media**: False "balance", and leap to hopelessness

↓↓3. **Special Interests**: Disinformation campaigns, emphasis on short-term profits

↓4. **Government**: Seems affected by special interests; fails to lead – no Winston Churchill today

↓5. **Public**: understandably confused, uninterested

Figure 45. The global warming story differs markedly from the ozone story. Scientists have perhaps not made clear the emergency that is upon us. Special interests have been particularly effective in affecting the media and governments so as to avoid actions needed to stem global warming.

As it appears that the world may pass a tipping point soon, beyond which it will be impossible to avert massive future impacts on humans and other life on the planet:

Who Bears (Legal/Moral) Responsibility?

1. **Scientists?**

2. **Media?**

3. **Special Interests?**

4. **U.S. Politicians?**

5a. **Today's U.S. Public?**

5b. **U.S. Children/Grandchildren?**

Who Will Pay?

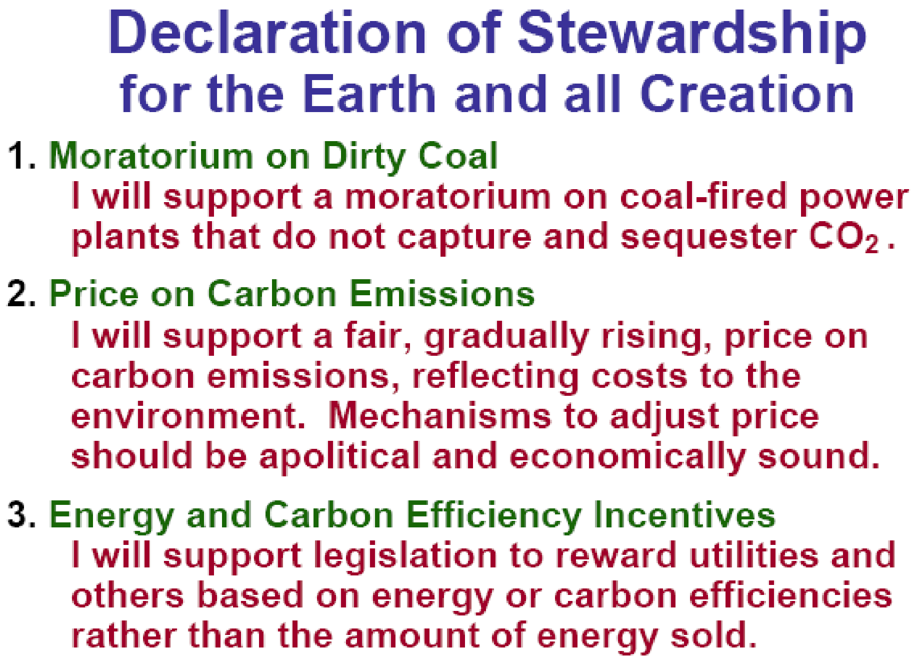
Figure 46. Responsibility for the current situation rests, in my opinion, with all of the parties 1 through 5a. Unfortunately it is the younger and future generations, bearing little if any responsibility, who will be faced with most of the consequences and will need to pay for our profligate use of natural resources.

Urgent Action Needed:

Moratorium on New Coal Powerplants
- Plant Lifetime ~ 50-75 Years
- Sequestration Technology ~10 Years Away
- Efficiency, Renewables in Interim
- Need to Remove Barriers to Efficiency

Citizens Must Stand Up
- Coal Industry is Very Powerful
- Congress Unlikely to Act Decisively

Figure. 47. By far the most important action needed to get the world onto a track that will stabilize climate is an immediate moratorium on new coal-fired power plants in the developed world, to be followed by a similar ban in developing countries within a decade.



Declaration of Stewardship
for the Earth and all Creation

1. Moratorium on Dirty Coal
   I will support a moratorium on coal-fired power plants that do not capture and sequester CO_2 .
2. Price on Carbon Emissions
   I will support a fair, gradually rising, price on carbon emissions, reflecting costs to the environment. Mechanisms to adjust price should be apolitical and economically sound.
3. Energy and Carbon Efficiency Incentives
   I will support legislation to reward utilities and others based on energy or carbon efficiencies rather than the amount of energy sold.

Figure 48. Failure of governments to take actions needed to preserve creation, and the priority that governments have given to special interests over the common good, make it clear that citizens need to place greater priority on preservation of creation in exercising their electoral prerogatives. Candidates for office have begun to make note of the climate issue and utter fuzzy words in support of the planet and the environment. However, actions proposed are, in most cases, ineffectual, not incorporating the two essential needs for stabilizing climate: phase-out of dirty coal and a gradually rising price on carbon emissions.

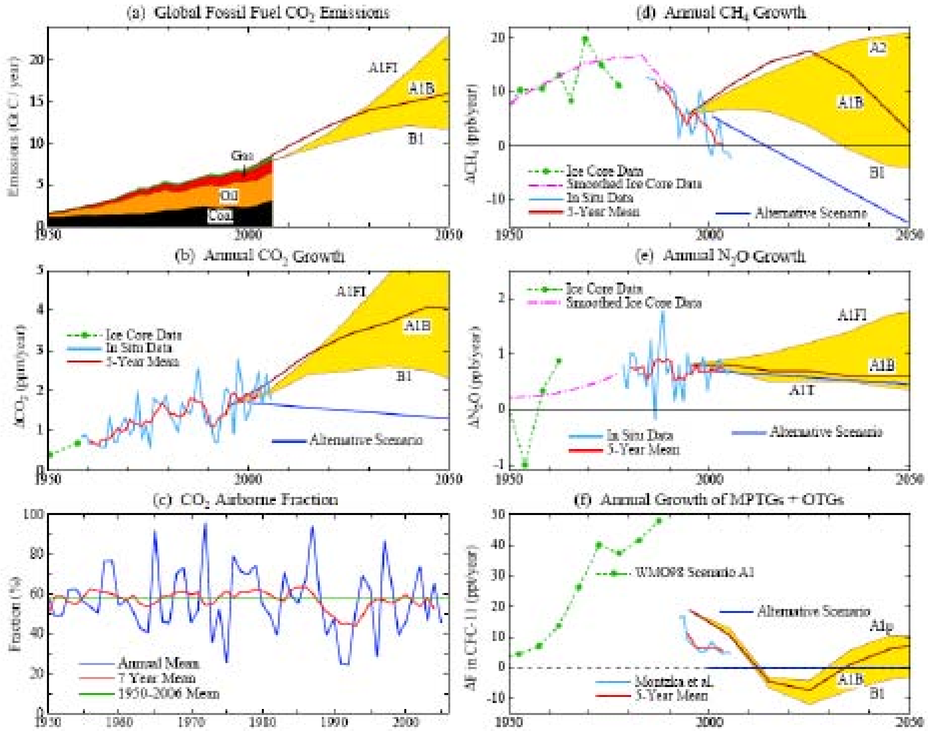


Figure 49. CO_2 emissions are increasing at a rate at or above IPCC “business-as-usual” scenarios. Other greenhouse gases are increasing at slower rates.

Climate Forcing by Long-Lived Greenhouse Gases

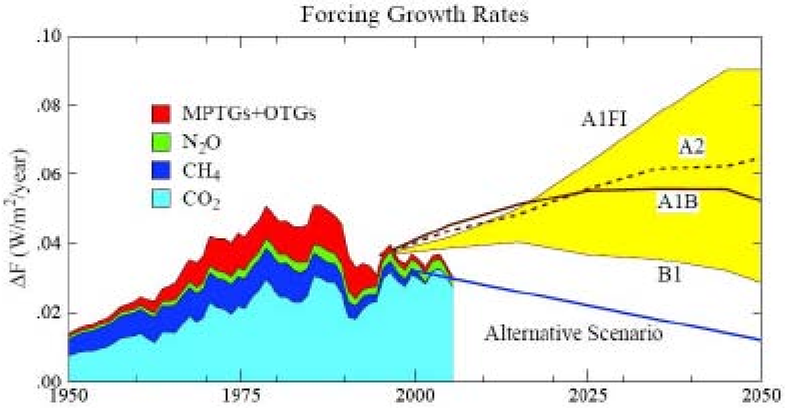


Figure 50. Climate forcing by all long-lived greenhouse gases is increasing at a rate that falls below all IPCC scenarios, about half-way between the IPCC and alternative scenarios. The last two point (2005 and 2006) on the observations may be somewhat misleading, as they are 3-year and 1-year means, while the other points are 5-year means. Because the 2006 CO_2 increase was relatively small, that decreases the 2005 and 2006 results, which may be modified when 2007 and 2008 allow full 5-year means to be calculated.

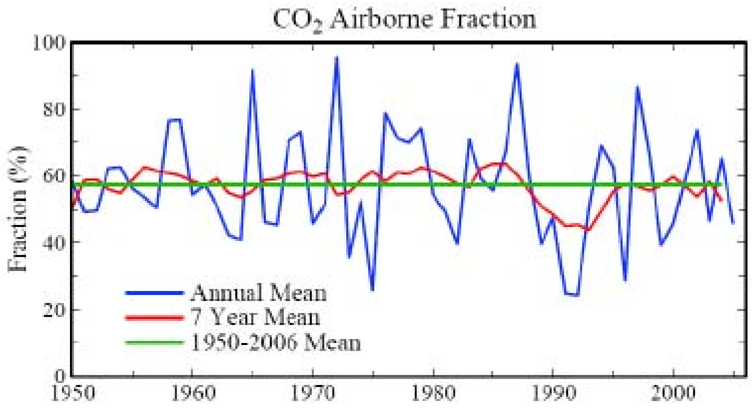
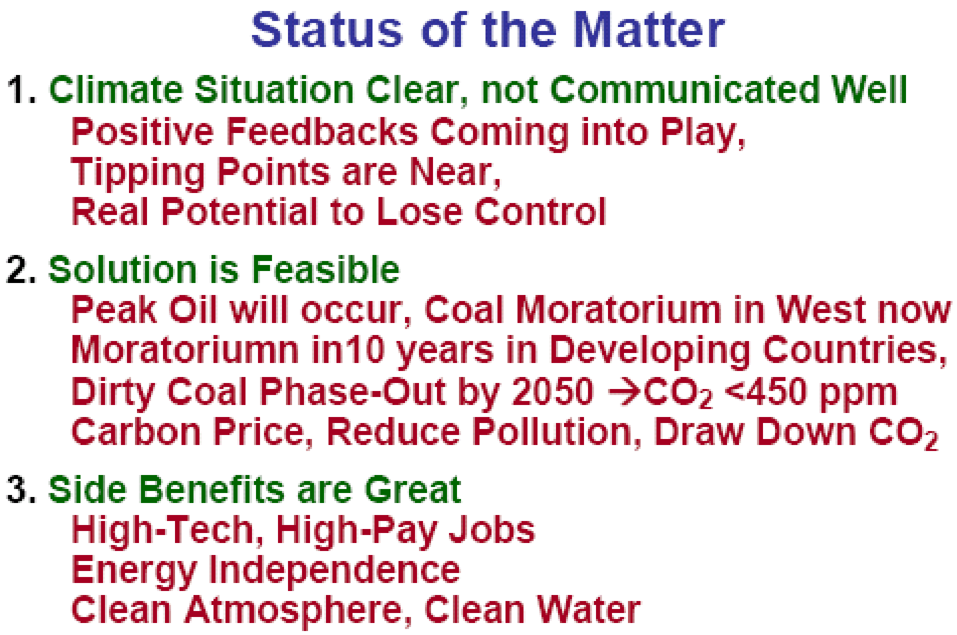


Figure 51. Ratio of annual increase of CO_2 in the atmosphere divided by annual fossil fuel CO_2 emissions. The long-term mean is ~58% with negligible trend.



Status of the Matter

1. **Climate Situation Clear, not Communicated Well**
   Positive Feedbacks Coming into Play,
   Tipping Points are Near,
   Real Potential to Lose Control

2. **Solution is Feasible**
   Peak Oil will occur, Coal Moratorium in West now
   Moratoriumn in10 years in Developing Countries,
   Dirty Coal Phase-Out by 2050 →CO_2 <450 ppm
   Carbon Price, Reduce Pollution, Draw Down CO_2

3. **Side Benefits are Great**
   High-Tech, High-Pay Jobs
   Energy Independence
   Clean Atmosphere, Clean Water

Figure 52. We have reached a climate crisis, but there are feasible actions that could defuse the global warming time bomb, and these actions have many ancillary economic and environmental benefits.

Personal Observations (opinions)

1. **Struggle Against Greed**
   - Special Interests Guard Short-Term Profits
2. **Struggle Against Ignorance/Misinformation**
   - Modest Progress Recently
   - Misconceptions are Shocking
   - Should be a Conservative Issue
3. **Best Hope**
   - Draw Attention to Generational Inequity
   - Watch Deeds, not Words

Figure 53. Based on experience, I believe that the difficulty in communication about global warming and the lack of success in obtaining actions needed to reduce global warming are, at least in part, a consequence of the role of special interests who seem to place inordinate priority on short-term profits. Although global warming has received much attention of late, there remains a shocking gap between what is understood by the relevant scientific community and what is known by those who need to know, the public and policy-makers. I find it puzzling that conservatives, and I consider myself to be a moderate conservative, are not more concerned about preserving creation. I believe that the best hope for achieving the actions needed to preserve climate for the benefit of all residents of the planet is to draw attention to the generational inequity, the burden that we could leave for our children and grandchildren, and for this jpurpose it is young people themselves who must understand the matter and help communicate with their elders. One word of caution: when fossil fuel companies start putting ‘green’ advertisements in the newspaper throw those in the waste bin straightaway and instead check what fraction of their earnings are being invested in energy sources that do not produce greenhouse gases.