The Basic Science of Climate Change

June 2004

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This report is intended to provide policy makers with the basic information and analyses underlying the international scientific consensus that climate has begun to change due to human activities.

Contents

Introduction [thanks to Jim]

The World Meteorological Organization reported that the four warmest years in weather-keeping history (since 1860) were 1998, 2002, 2003 and 2001, and the 10 warmest years in the 20th century have occurred since 1991. These data tells us that change in Earth's temperature, like that of the atmospheric concentrations of greenhouse gases, is accelerating. The WMO also concluded that the enhanced weather variability – storm, drought and heatwave intensity – were due to the increased heat accumulating in the atmosphere and oceans.

New satellite analyses from NASA indicate large warm anomalies across much of the Arctic over the past decade. New sea ice analyses confirm that the Arctic warmed much faster during the 1990s than in earlier decades. New interpretations of decades of North Atlantic Ocean data show recent changes in circulation that are consistent with global warming.

Earth's average temperature means very little in our everyday lives. It is simply a conveniently computed statistic for the state of the global climate. In 2003, for example, some areas had unusually cold periods. But the average for the year tells us that even more of Earth's surface was unusually warm.

Natural ecosystems, which among other things are the ancestral sources of species that we manage for crop, dairy, and meat production, all evolved under climate regimes that are now being supplanted by new conditions, mostly warmer, some wetter and some drier, and some rapidly alternating between wetter and drier. World Watch reports that global grain harvest has failed to meet demand for each of the last four years. In China, as in many nations, warmer weather has exacerbated the growing water crisis and has resulted in reduced crop yield. The annual shortfall in China is now equivalent to the entire annual grain production of Canada. If this trend continues China will soon become a major importer of grain.

Over the past two million years Earth's climate has cycled about a dozen times between periods of cold and warm conditions. The species on Earth today have thrived because they can accommodate to a wide range of temperatures. However, today's temperature extremes are taking these species into uncharted territory. In many areas the unusually warm conditions of the last few years are bumping up against upper temperature limits for reproductive success and yield at harvest for some of our most important grain crops.

Similarly, our social and economic systems have evolved to accommodate efficiently a range of temperatures experienced over an annual cycle. Some areas are too hot in the summer for extended outdoor daytime labor, and because of this residents have adjusted daily activity cycles accordingly.

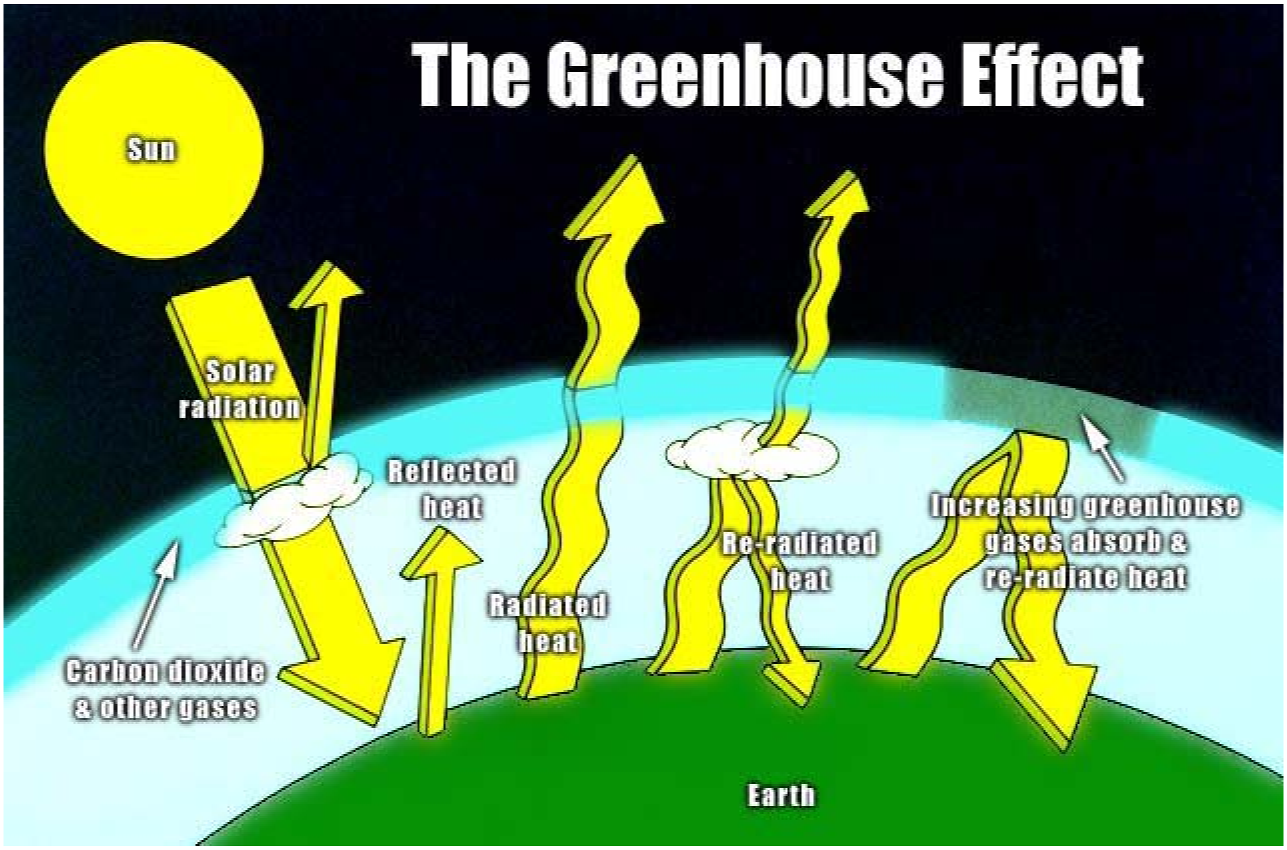
In the summer of 2003 a heatwave in Europe demonstrated just how close our current infrastructure and social systems are to critical thresholds for human habitation. Heat-related deaths in five European nations reached 35,000, and unpublished studies have found that most of the deceased were not likely to have died soon from other causes. Temperatures in Portugal reached 117 deg F, and widespread wildfires and crop failures accompanied the human tragedy. The toll from such a heatwave in the Eastern US would be enormous.

As Earth warms more of its frozen water becomes liquid and more of its liquid water vaporizes, which can be carried a long way from the source since a warmer atmosphere holds more moisture. Where and how heavily this moisture falls as precipitation is another aspect of climate change that has enormous potential to tax our existing agricultural systems and urban infrastructure. Dry conditions in the West in 2003 were contributing factors in the S. California wildfires -- the most costly ever in the U.S. -- that, in turn, created conditions leading to the succeeding floods.

1. <u>First Principles – chemistry and physics</u>

Carbon dioxide (CO_2) in the atmosphere traps heat (outgoing infrared radiation). (Incoming sun rays are in the ultraviolet spectrum.) Without this layer of insulation – the natural "greenhouse effect" -- temperatures on Earth would be about -17^{o}C. Thus, increased CO_2 in the inner atmosphere (or troposphere, ~ 6 miles up) is exaggerating the natural greenhouse effect and increasing heat trapped in the troposphere.

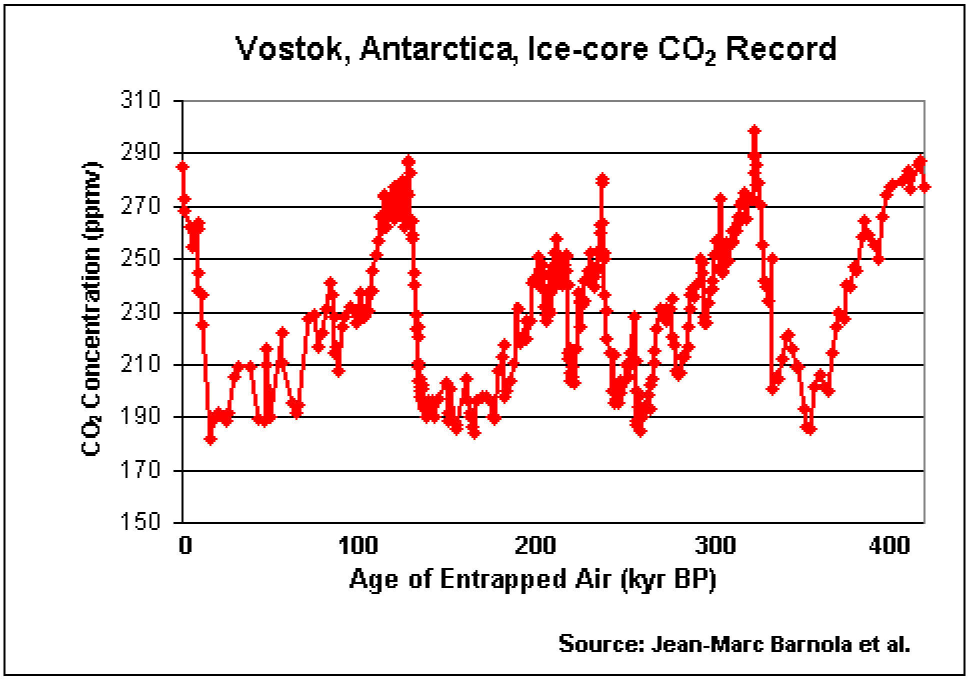
Over the past several decades the troposphere has actually swollen several hundred feet due to the warming and thermal expansion of the air.



Ref

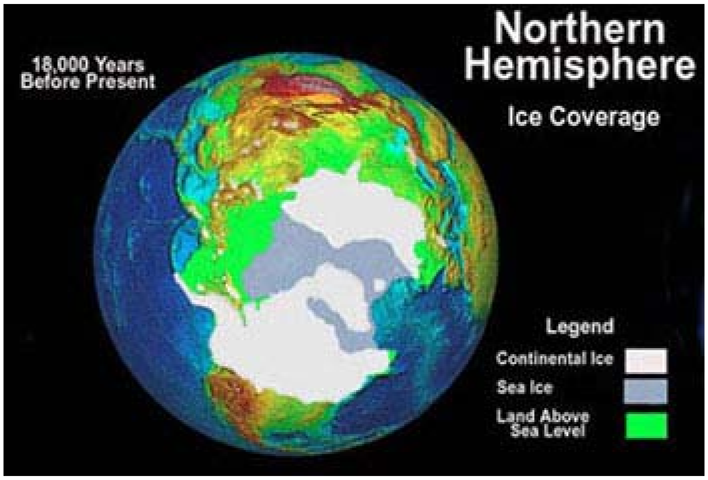
Contributions of Anthropogenic and Natural Forcing to Recent Tropopause Height Changes. B. D. Santer, M. F. Wehner, T. M. L. Wigley, R. Sausen, G. A. Meehl, K. E. Taylor, C. Ammann, J. Arblaster, W. M. Washington, J. S. Boyle, and W. Brüggemann. *Science* 2003 July 25; 301: 479-483.

2. <u>The Vostok Ice Cores</u>



The two mile long ice core taken from Vostok, Antarctica indicate that CO_2 levels (and average global temperatures) have fluctuated within a narrow envelope for at least 420, 000 years. CO_2 have alternated between 180 parts per million (ppm) and 280 ppm; the lower number during glacial maximums; the higher number during warmer interglacial periods (like the present).

The levels have probably been in this envelope for 2 million years, when movement of tectonic plates created the Gulf Stream and Earth's climate moved into the modern period of ice ages – alternating between <u>large</u> polar ice caps (see figure) and <u>medium</u> size caps, like those of today.



Today North Polar ice is melting and we may be heading for a third state, with very small ice caps; unless the warming trend is interrupted by a “cold reversal,” as has occurred several times in the past according to the ice core records (see below).

High-resolution ice core records (with yearly changes now detectable in thin layers) indicate that increased variability and volatility preceded the most recent “cold reversal,” known as the Younger Dryas (11,500 to 12,700 years ago).

Refs

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Thomas R. Karl and Kevin E. Trenberth
Science 2003 December 5; 302: 1719-1723

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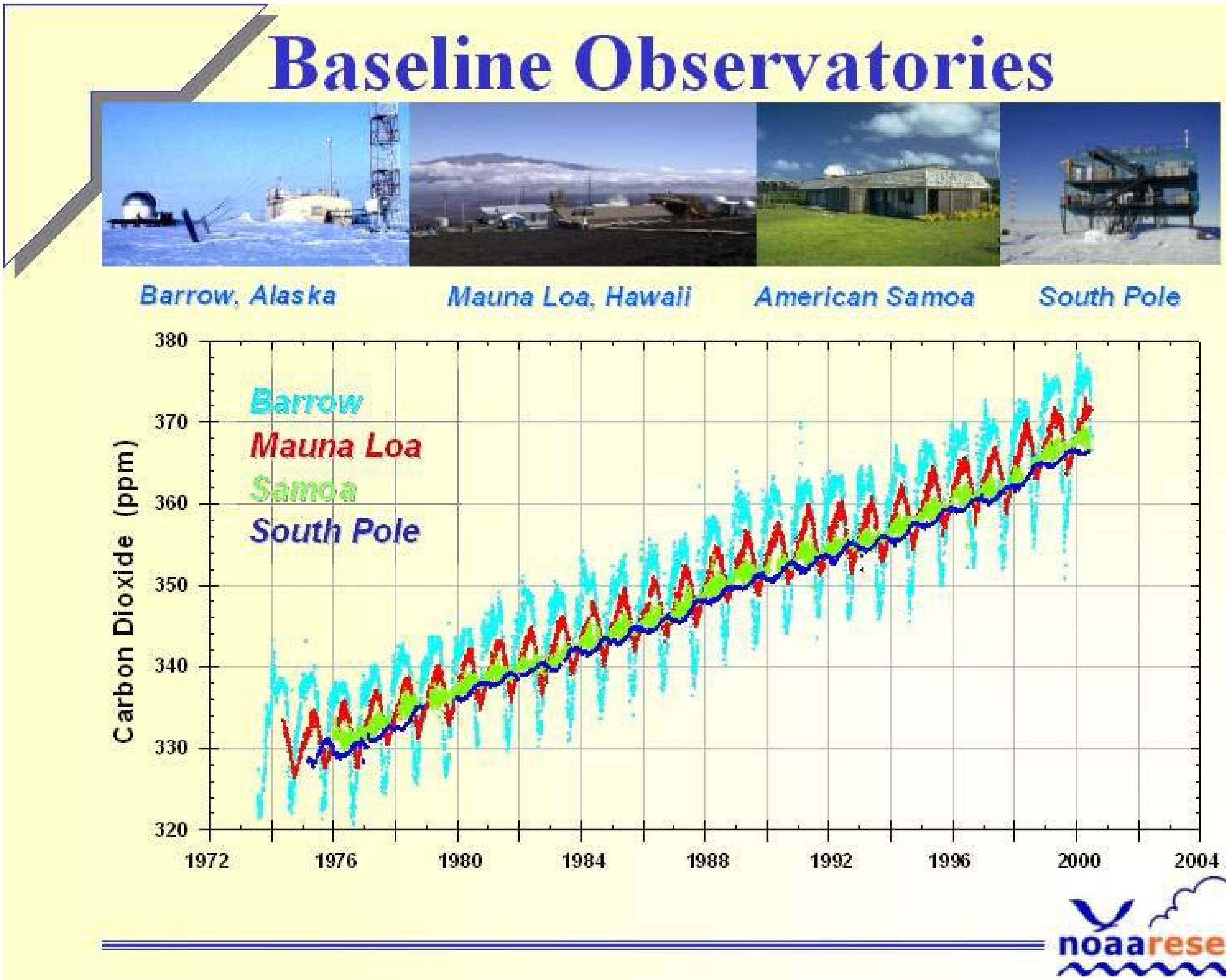
3. Carbon Dioxide

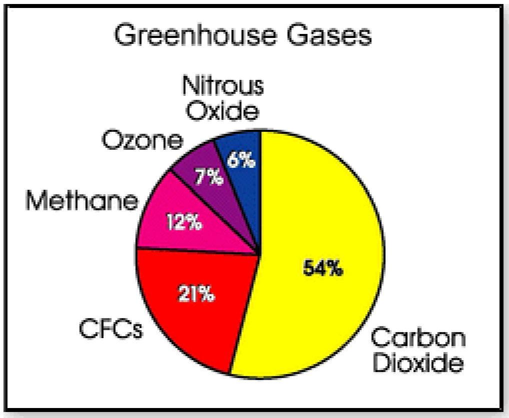
CO_2 emissions are long-lived and remain in the atmosphere for ~100 years. Since 1957 – the first International Geophysical Year that initiated global change research – Prof. Keeling set up the measurements of atmospheric CO_2 at a station on top of Mauna Loa in Hawaii. That record – joined by several others (below) -- has produced the basic information upon which rests our understanding and the general circulation models of the climate system.



Today CO_2 levels are 372 ppm (i.e., 30% above pre-industrial levels). The natural carbon cycle involving 100s of ppm of CO_2 releases and land and ocean sinks. But the 6 billion tons of carbon released each year by human activities (that's one ton per person on Earth) is enough to overwhelm the sinks and is steadily building up in the atmosphere. There is evidence that, as the oceans warm, they will hold less CO_2, one of several potential feedbacks from warming that may contribute accelerated warming (see below).

Total **greenhouse gases** (CO_2, methane, oxides of nitrogen or NO_xs, Chlorofluorohydrocarbons or CFCs, and ground-level ozone or smog) are also rising. All of these gases have "Global Warming Potential," thus the "CO_2-equivalent" (the total heat-trapping occurring) is significantly higher than 30% above pre-industrial baselines (IPCC 2001).

Figure 2



[CO_2 and other greenhouse gases have been relatively stable for the past 10,000 years the Holocene) since the last ice age. Recent work by Ruddiman hypothesizes that some CO_2 was released by human activities 8000 years ago and methane was released from rice cultivation some 5000 years ago [clarify]. But the buildup in the 20th Century surpasses the fluctuations seen even during the relatively stale Holocene.]

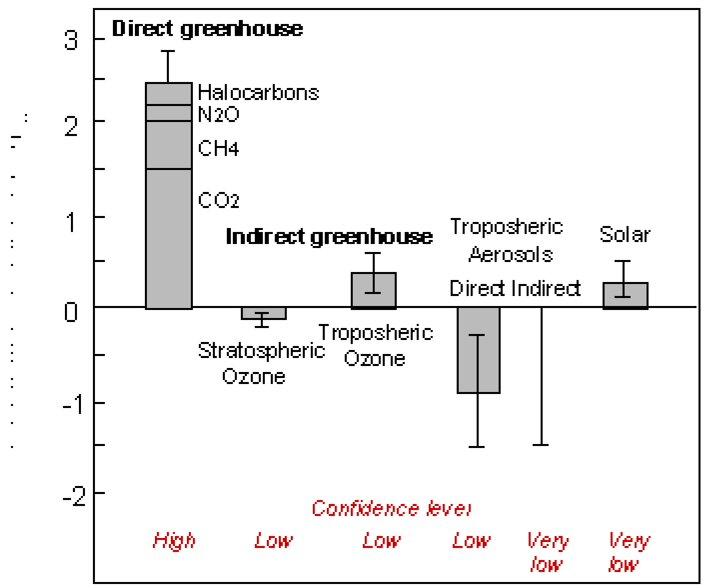
4. The role of aerosols, clouds and water vapor

The precise role that clouds will play is one of the areas of uncertainty. Aerosols, such as oxides of sulpher (SO_xs), counteract warming by seeding clouds and reflecting incoming sunlight. SO_xs constitute Cloud Condensation Nuclei around which clouds form, but they are short-lived in the atmosphere (~ 8 days). Sulpher (DMS or dimethyl suphide) released from dying plankton is a natural source; sulphates from combustion of coal and oil are anthropogenic sources.

Low clouds tend cool Earth's surface by reflecting incoming solar rays and producing rain. High clouds tend to warm Earth's surface by trapping outgoing infrared (heat) waves. Over all water vapor (humidity) is increasing in the atmosphere due to:

a. Greater evaporation from warmer oceans;
b. Greater evapotranspiration from land surfaces and plants due to atmospheric warming; and
c. Greater holding capacity of a warmer atmosphere; the air can hold 6% more water vapor for each 1^{o}C warming.

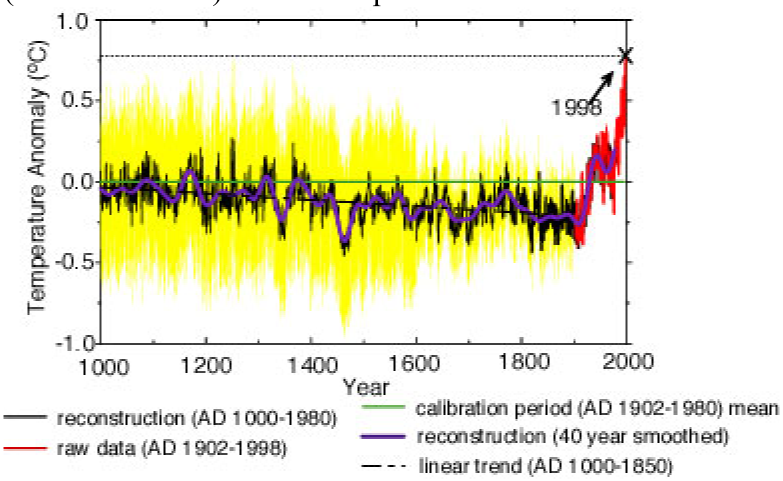
Water vapor accounts for 60% of the greenhouse effect (CO_2 contributes 25%). The cooling by aerosols is accounted for in the current General Circulation Models (GCMs). Thus, overall, despite uncertainties about the negative and positive affects of clouds, increased water vapor in the atmosphere is projected to increase overall atmospheric warming.



From Climate Change 1994: Radiative Forcing of Climate Change and An Evaluation of the IPCC IS92 Emission Scenarios". J.T. Houghton, L.G. Meira Filho, J. Bruce, Hoesung Lee, B.A. Callander, E. Haites, N. Harris and K. Maskell (Eds). Cambridge University Press, UK. 339pp. (ISBN: 0-521-55962-6).

5. The Past 1000 Years

Temperature records from the past 10,000 years are gleaned from tree rings, plankton deposits, pollen and plant deposits, insect fossils, fish otoliths (inner-ear bones) and other "paleothermometers."

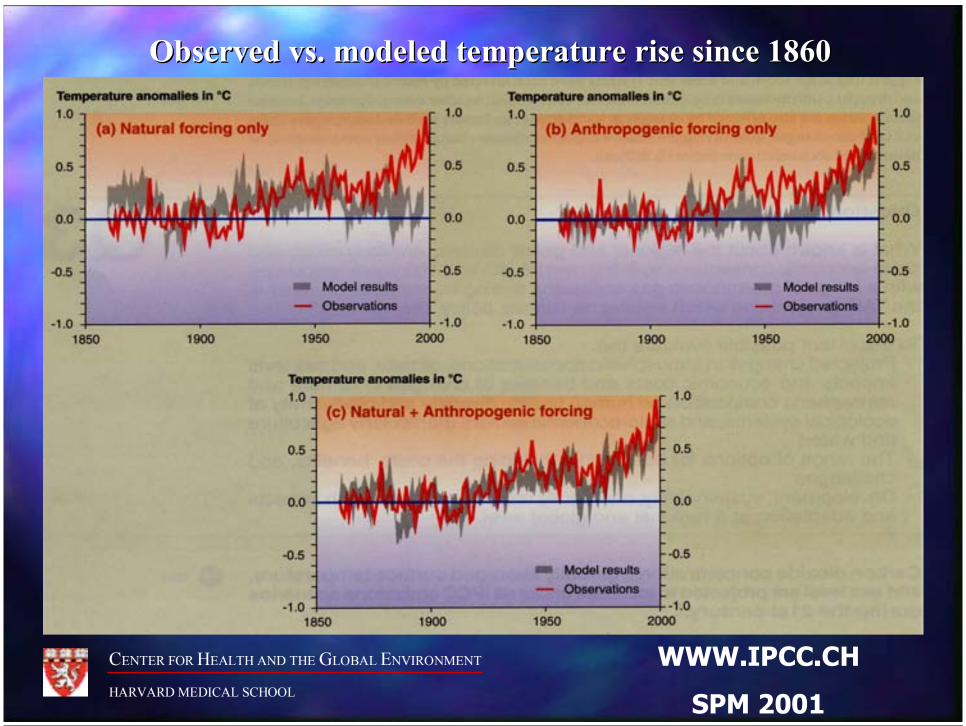


That record depicts a gradual cooling with marked, accelerating warming over the 20th Century (see orbital cycles below). The cooling trend from ~1940 to the mid 1970s may have been due to increased sulphates in the atmosphere and ocean absorption and turnover (convection), burying heat in the deep ocean.

Ref

M. E. Mann, R. S. Bradley, M. K. Hughes, *Geophys. Res. Lett.* **26**, 759 (1999).

5. The Twentieth Century



Natural variability alone does not account for the significant warming, especially that which occurred during the last half century.

The graphs above show the data on temperature trends for the past 150 years. The gray line is the actual measurements and is the same in all three graphs. The best fit – the best explanation – for the observations is derived by combining natural variability (upper left) and human influences (upper right).

The graphs of temperature measurements also depict the increasing rate of warming -- ~ 3°C/ per Century -- in the latter part of the 20th Century, compared to the overall trend of ~ 1°C/per Century for the entire period. The rate of warming is accelerating and 10 of the hottest years of the past 150 occurred between 1991 and 2003.

Ref

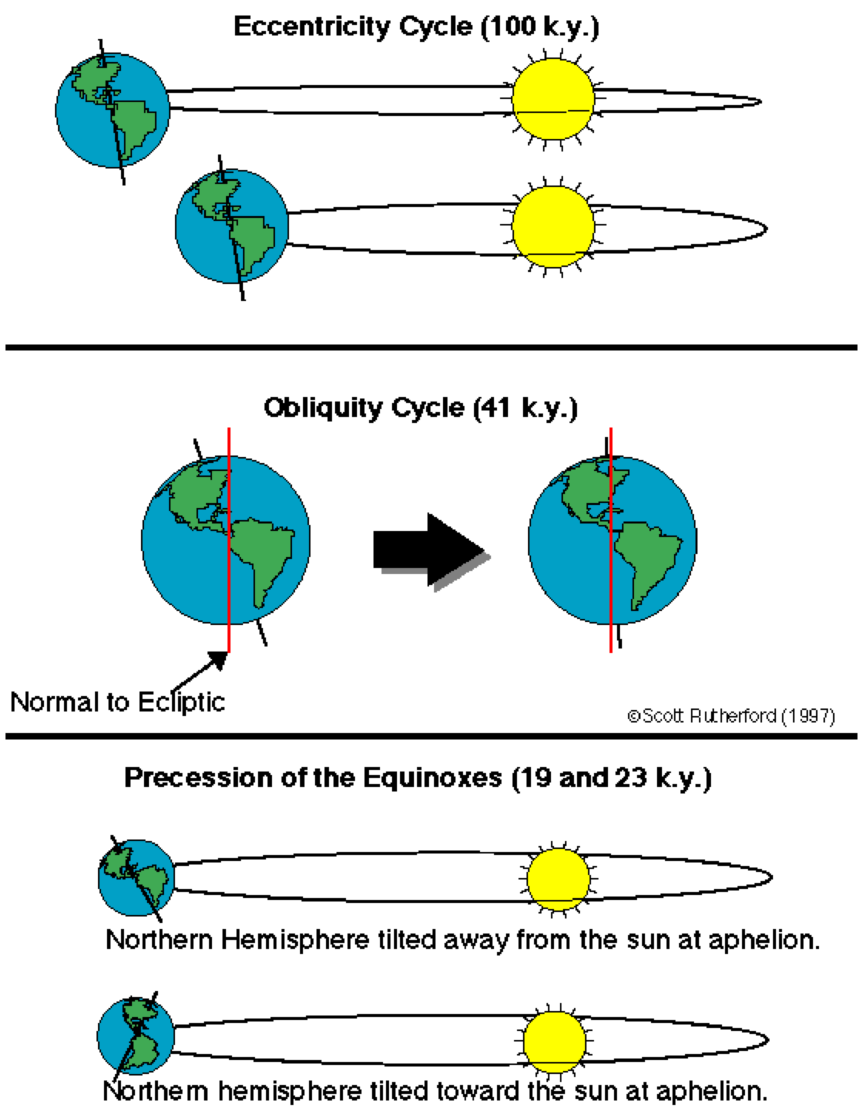
King, David A.
ENVIRONMENT: Climate Change Science: Adapt, Mitigate, or Ignore?
Science 2004 303: 176-177

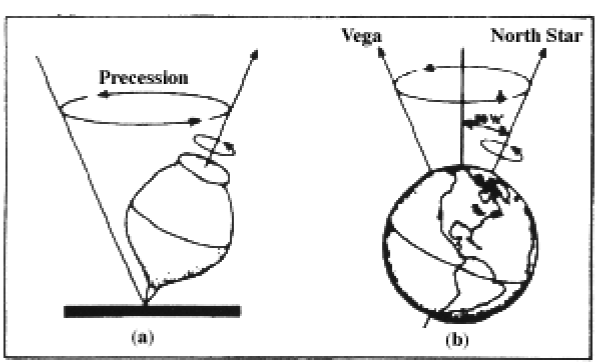
7. Orbital (Milankovitch) Cycles

Tilts and wobbles of Earth's axis and changes in the elliptical cycle and the distance of earth from the Sun are the primary drivers of ice ages and warmer states in Earth's climate. Volcanoes and movement of tectonic plates are the other driving factors.

There are actually six types of tilts, wobbles and eccentricities, each with different periodicities. Precession (the bottom panel) -- is ~22, 000 years, meaning that warm and cold cycles have a strong 11,000 year signal. 11,000 years ago Earth's axis was tilted towards the sun when it came closest to the sun. Rivers flowed in the Sahara Desert. Today, the sun beats directly on the open southern ocean where heat is absorbed; and the Northern Hemisphere remains cooler.

The Milankovitch cycles, changes in solar radiation, volcanic eruptions and movement of tectonic plates account for the observations in climate (paleoclimate) records. Until the 20th Century, that is, when the data can only be explained by combining this natural variability with the heat-trapping effects of greenhouse gases (GHGs; see chart above in number 6).





The harmonics of the six waves (over time) drive the climate changes. For the past 420, 000 years ice ages lasted about 100,000 years while interglacials lasted about 10,000 years. Before 420, 000 years the ratio may have been different and according to the most recent calculations, the Holocene (the relatively stable and hospitable period -- ~15^{o}C for average global temperatures -- that has lasted for 10, 000 years) was not about to end any time soon.

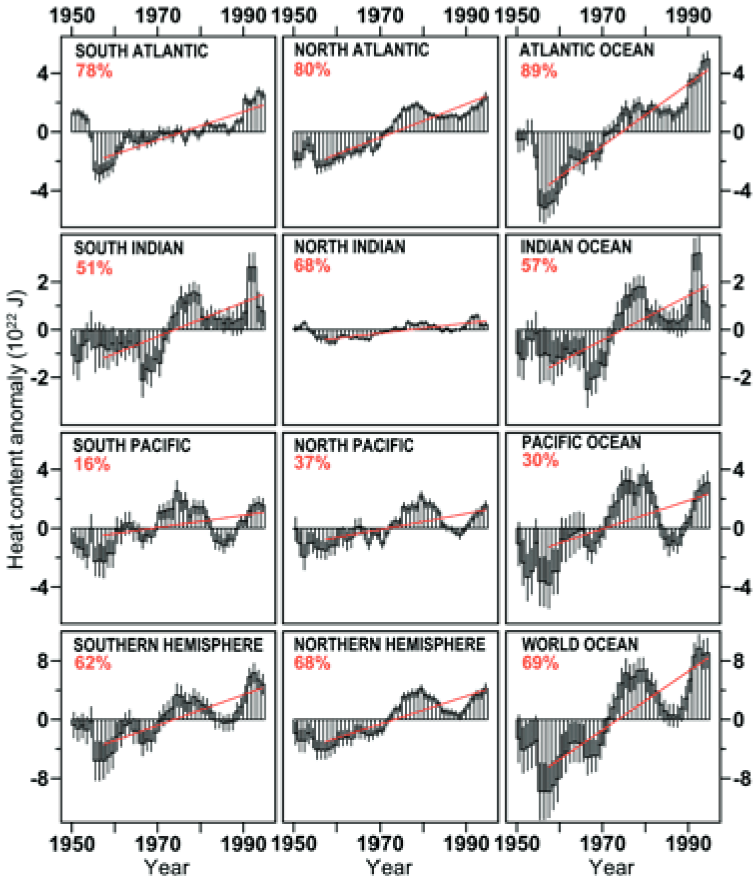
Thus, the idea that anthropogenic warming may be saving us from the coming ice age appears unfounded. Indeed, the opposite may be true, due to the potential for a "cold reversal" in the current warming trend.

Ref
An Exceptionally Long Interglacial Ahead?
A. Berger and M. F. Loutre
Science 2002 August 23; 297: 1287-1288.

8. <u>Deep Ocean Warming and Extreme Weather Events</u>

In the past 50 years the top two miles (half way) of the ocean has warmed. This has changed the hydrological (water) cycle. Evaporation has increased from the oceans and the land, intensifying droughts and creating the conditions for heavier downpours (>2"/day). In addition to overall warming and disproportionate warming in winter and near the poles, intensification of droughts, heatwaves and floods are central drivers of the agricultural, water system, forestry, marine system and human health consequences of climate change. [Other impacts need to be expanded.]

a. Epstein PR. Climate and health. *Science* 1999: 285: 347-348.
b. Trenberth, K.E., 1999: The extreme weather events of 1997 and 1998, *Consequences* **5**, 3-15.



[Time series of 5-year running composites of heat content (10^{22} J) in the upper 3000 m for each major ocean basin. Vertical lines represent ±1 SE of the 5-year mean estimate of heat content. The linear trend is estimated for each time series for the period 1955 to 1996, which corresponds to the period of best data coverage. The trend is plotted as a red line. The percent variance accounted for by this trend is given in the upper left corner of each panel. Expanded versions of these figures with equivalent volume mean temperature scales added can be viewed at *Science* Online.]

9. <u>"Cold Reversals:" The Potential for Abrupt Climate Change</u>

Warming of the atmosphere is also occurring disproportionately at high latitudes and the combination is changing the North Atlantic. In summers, since the 1970s, North Polar ice has shrunk from ten to five feet thick while Greenland is losing 9% per decade.

Greenland ice melt water is trickling down through crevasses, lubricating the base, speeding up "ice rivers," increasing the potential for slippage. And towards the South Pole, disintegrating ice shelves -- like sand slipping into the ocean, taking pressure off the dunes – is taking back pressure off the land ice on the Antarctic Peninsula.

The North Atlantic Deep Water Pump – the sinking cold, *salty* water that pulls the Gulf Stream north – is slowing, as thawing ice and more rain falling at high latitudes leave cold, *fresh* water that does not sink. At the same time, the tropical Atlantic is becoming saltier, as ocean warming increases net evaporation and rain falling at high latitudes. Melting ice and rain falling to the north is layering cold, fresh water across the North Atlantic. (Cold, *salty* water sinks, pulling the warm Gulf Stream north; the deep water pump that drives the ocean conveyor belt that has stabilized climate for millennia.)

Freshening is already having an impact. The accompanying North Atlantic "high" helps accelerate transatlantic winds (polar winds are also affected by stratospheric conditions) and the resulting deflection of the jet stream south helps drive arctic air in winters down the US Atlantic coast and across to Europe and Asia.

The North Atlantic Ocean can freshen to a point where the deep water pump fails. Ice cores demonstrate that "cold reversals" have interrupted other warming trends. In the Younger Dryas (11,500 to 12,700 years ago) the warming, melting and freshening apparently forced the Gulf Stream to shoot right across to France (as detected by plankton deposits) and ice formed across the Northern Atlantic – putting us back into an ice for some 1,300 years before it all warmed up due to the orbital cycles. High-resolution ice core records (with yearly changes now detectable in the thin layers) also indicate that increased variability and volatility preceded this most recent "cold reversal."

Since the 1950s the deep overflow between Iceland and Scotland has slowed by 20%.

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10. The Intergovernmental Panel on Climate Change (IPCC)

The study of the causes of climate change is a study with an *n* of 1 (i.e., there is only one Earth). That means there is no control for the study of Earth's climate and the study cannot be repeated. Thus, the study requires analysis of trends and mapping of patterns. The primary tool for doing this analysis is the comparison of data (observations) with model projections. When data matches the outcomes of GCMs that are driven by rising GHGs, these are called "fingerprint" studies.

Three fingerprint studies were central to the IPCC Second Assessment Report of 1996.

1. Greater warming was occurring in the mid-troposphere (several miles up) than at the Earth's surface (in mountain regions);
2. Nighttime and winter temperatures (daily and yearly -- temperature minimums) were warming at twice the rate of overall warming; and
3. Extreme weather events were intensifying (more prolonged droughts, heatwaves and more heavy downpours [>2"/day]) were occurring over the 20th Century.

These three studies – where observations matched predictions -- led to the famous conclusion that GHG emissions were having a "discernable" influence on Earth's climate.

By the time of the IPCC Third Assessment Report in 2001, there were additional fingerprint studies, including:

1. Accelerating melting of mountain glaciers and ice near both Poles;
2. Increased circumpolar wind speeds around the North Pole;

   And, in 2003,

3. Increased circumpolar winds were detected around Antarctica as well.

   And an expanding set of biological responses

4. Latitudinal and altitudinal shifts of land animal and plant species, marine species, timing of bird egg-laying (and timing of seasons), consistent with the warming trends (i.e., shifts in freezing isotherms towards the poles and to higher altitudes).

The accumulation of fingerprints of climate change generated the consensus statement (including the governments of oil producing nations) that "…most of the observed warming over the past 50 years is likely to have been due to the increase in greenhouse gas concentrations" (IPCC 2001 Summary for Policymakers; www.ipcc.ch).

Analysis

Climate scientists are increasingly concerned that climate is changing much faster than models projected just several years ago. The same dynamic was true for the "ozone hole." When it was detected by satellite images in the early 1980s scientists were shocked to find that the models had vastly underestimated the true extent of the loss.

Several "positive" (warming-enhancing) feedback mechanisms appear to be playing significant roles. These include:

a. Increasing atmospheric water vapor;

b. Decreased ice albedo

   Ice reflects incoming solar radiation. This reflectivity is called "albedo." As ice melts, albedo decreases and there is more ocean surface exposed to absorb more heat; and this can accelerate the rate of change.

c. The greatly disproportionate warming occurring in boreal areas (Canada and Siberia) and near the poles relative to the winter warming in tropical and temperate latitudes;

d. Decreased forest cover (i.e., reduced carbon "sink"), fires (carbon pulses), and the warming role of particulates (e.g., extensive "brown haze" over Asia);

   and (perhaps the most significant)

e. The models (GCMs) omit the global warming potential role of the other GHGs -- NO_xs, methane, CFCs, ground–level ozone (photochemical smog) – that, in sum, have increased the overall CO_2–equivalent warming to some 50-60% over pre-industrial conditions. That is, we are closer to doubling the global warming potential of GHGs than is reflected in the models based solely on CO_2 concentrations.

These factors taken together may help explain the increasing rate of change and the previous underestimates of the biological, social and economic consequences of warming and the associated intensification of weather extremes.

The established (i.e., certain) connections between changes in atmospheric chemistry, Earth's heat budget (physics), the hydrological cycle and the biological (and social) systems, plus the magnitude of risk climate change has the potential to deliver, constitute the essential ingredients for invoking the *Precautionary* Principle, which implies taking early, preventive actions involving global cooperation, aimed at stabilizing the climate.

Ref

IPCC 2001: Houghton, J.T., Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, K. Maskell and C.A. Johnson, eds. 2001. Climate Change 2001: The Scientific Basis. Contributions of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press.

11. Climate Change and Human Health (Summary)

Climate change has multiple direct and indirect consequences for human health. Heatwaves are the most direct and are projected to take an increasing toll in developed and underdeveloped nations. The 2003 summer heatwave in Europe, with 35,000 excess deaths in five nations, extensive wildfires and widespread crop failures demonstrates that climate change and the magnitude of its impacts may be surprisingly non-linear.

Climate also restricts the range of infectious diseases, while weather affects the timing and intensity of outbreaks. The ranges of several key diseases or their vectors are already changing in mountainous regions, along with upward shifts in plant communities, the rapid retreat of alpine glaciers and an upward shift in the freezing isotherm (the level at which temperatures remain below freezing all year).

Deep ocean warming is accelerating the hydrological cycle and the associated extreme weather events (EWEs) can create conditions conducive to outbreaks of infectious diseases. Heavy rains can leave insect breeding sites, drive rodents from burrows and contaminate clean water systems. Conversely, drought can spread fungal spores, spark fires (and respiratory illness) and is statistically associated with large outbreaks of West Nile virus and St Louis encephalitis, a disease with a similar life cycle.

Sequences of extremes can destabilize predator/prey relationships, leading to population explosions of opportunistic, disease-carrying organisms (e.g., rodents and mosquitoes). The 1997/98 El Niño-related extreme weather events spawned "clusters" of disease outbreaks in many regions of the globe.

In the marine environment, ocean warming – along with eutrophication and loss of filtering wetlands -- is contributing to harmful algal blooms that can cause shellfish poisoning, provide a reservoir for cholera and other bacteria, and can lead to hypoxia and "dead zones".

Excess carbon dioxide itself has consequences for organisms. Ragweed grown in elevated carbon dioxide levels produces a lot of pollen. Opportunistic, weedy plants take advantage by allocating CO2 to reproduction - the male parts - whereby they spread and prosper. Pioneering trees that spread quickly - like maples, pines, birches, and poplars - also appear to be boosting their seeds, cones, and pollen.

Advances in climate forecasting and health early warning systems can help catalyze timely, environmentally-friendly public health interventions. If climate change continues to be associated with more volatile and severe weather, we have begun to see the profound consequences climate change can have for public health and the international economy.

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- Wayne P, Foster S, Connolly J, Bazzaz F, Epstein P. Production of allergenic pollen by ragweed (*Ambrosia artemisiifolia* L.) is increased in CO_2-enriched atmospheres. *Annals of Allergy, Asthma and Immunology* 2002;8:279-282.

12. Life Cycle of Oil: Health, Ecological Dimensions

While oil and the energy it supplies provide many benefits to human society, every stage in the life cycle of oil exploration and use carries hazards for the wildlife and humans. Extraction and transport have impacts on natural systems, such as the Niger River Delta and the headwaters of the Amazon in Ecuador, while oil spills (e.g., in the Galapagos) and leaks along coastlines pose risks for marine life, fisheries and for tourism. Refining and combustion generate air pollution and acid rain, and the combined emissions are altering the planet's climate system.

When oil was first exploited, it appeared to be an unending source of natural energy. We now understand that the supply of oil is finite and that its use can have harmful affects on both local and global environments. In this report we examine the life cycle of oil: the exploration, drilling, extraction, transportation, refining and combustion of this fossil fuel. A brief summary follows.

Drilling and extraction can present acute hazards, including fires and blowouts, as well as chronic hazards, including occupational injury and disease and long-term harm to ecosystems, plant and animal communities. Transportation via tankers and though pipelines can cause environmental damage through large spills, while chronic oil leakage into soils and into the oceans may have even greater impacts on flora and fauna. Refining exposes workers and the environment to petroleum, its by-products and the chemicals used in refining. At the pump, gasoline can be both toxic and carcinogenic. Finally, the combustion of oil produces a set of products that affect the environment. By-products of gasoline combustion include VOCs, NO_xs, CO, PM-10s, PM-2.5, SO_xs and Pb (definitions below), chemicals that are toxic in a variety of ways to humans, other animals and plants. Acid rain has terrestrial impacts on forestry and wildlife; on aquatic and marine systems, affecting fisheries and leading to eutrophication.

Moreover, greenhouse gases are changing the global climate system, raising land and ocean temperatures and altering global weather patterns and the world's water cycle.

These profound changes in the stability of the climate system has direct implications for human health, agricultural productivity, societal infrastructure and economic viability. Climate change and extreme weather events (especially floods and prolonged droughts) also threaten increasingly fragile ecosystems (e.g., fragmented forests and depleted coastal wetlands), and for the already endangered species dependant upon the integrity and health of the mosaics of habitats.

Finally, dependence on oil throughout the past century has affected the social fabric within nations that have oil reserves, and is the huge amount of wealth associated is now manifesting an overwhelming impact on international relations.

13. Climate Change, Oil Life Cycle and Environmental Justice (Outline)

Vulnerabilities
- coping
- adaptation
- restoration
- prevention
- public health infrastructure

Oil-related health consequences

- Extraction: Nigeria, Ecuador, Mexico
- Refining & benzene
- Utility plants & mercury
- Air pollution
    - Inner city truck and bus routes
    - Pollen, ragweed and abandoned lots (higher city temps and Co_2)

Climate Change
- Extreme weather events
- Economic inequities

14. The costs of Climate Change

Warming of the atmosphere, land surface and ocean are associated with more extreme weather events (such as heatwaves, prolonged droughts, heavy downpours). The impacts of EWEs also have economic consequences. Yearly losses increased from $4 billion annually in the 1980s to $40 billion in the 1990s; reached $55 billion in 2002 ($11 billion insured) and $60 billion ($15 billion insured) in 2003. The United Nations Environmental Programme estimates that annual losses from extreme weather events could reach $150 billion by the end of this decade if current trends continue and this influenced the assessment of risks and opportunities for the insurance and reinsurance sectors.

15. Opportunities and Oil Independence

Changing course and developing clean energy sources around us will require new regulations and new "carrots" (incentives). The opportunities include greater energy efficiency, renewable energy sources, smart technologies to insure a safer grid, distributed means of power generation (fuel cells, wind turbines and solar panels), "green buildings," bicycle paths throughout cities, urban gardens and better systems of public transport. These enterprises can be the engine of growth for the 21st century, and the combined effort help stabilize the climate, protect the environment and revitalize the global economy. Oil independence can also increase national security and reduce international conflict. Oil independence and an end to coal mining and combustion are necessary first steps towards ensuring a healthier, more equitable and sustainable future.

15. Conclusions

Climate change is occurring and is occurring at a rate faster than projected just a half a decade ago. While we underestimated the rate of change, we also underestimated the responses of biological and economic systems to the warming and the associated intensification of weather extremes. But there are opportunities for tremendous economic growth with clean technologies – for new enterprises, jobs and trade, and the creation of clean and healthy living conditions, conducive to sustained growth.

To stabilize the *concentrations* of GHGs we must decrease the *emissions* of GHGs by some 60% over the coming years. Half of this may be achieved with greater energy efficiency. The rest will require public private collaboration on a grand scale and a framework with incentives for governments (D. King ref above) and international governance structures to reprogram and redirect development.

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