Can We Still Avoid Dangerous Human-Made Climate Change?*

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The Earth's temperature, with rapid global warming over the past 30 years, is now passing through the peak level of the Holocene, a period of relatively stable climate that has existed for more than 10,000 years. Further warming of more than 1ºC will make the Earth warmer than it has been in a million years. "Business-as-Usual" scenarios, with fossil fuel CO_2 emissions continuing to increase ~2%/year as in the past decade, yield additional warming of 2-3°C this century and imply changes that constitute practically a different planet.

Multiple lines of evidence indicate that the Earth's climate is nearing, but has not passed, a point or no return, beyond which it will be impossible to avoid climate change with far ranging undesirable consequences. The changes include not only loss of the Arctic as we know it, with all that implies for wildlife and indigenous peoples, but losses on a much vaster scale due to worldwide rising seas. Sea level will increase slowly at first, as losses at the fringes of Greenland and Antarctica due to accelerating ice streams are partly balanced by increased snowfall and ice sheet thickening in the ice sheet interiors. But as Greenland and West Antarctic ice is softened and lubricated by melt-water and as buttressing ice shelves disappear due to a warming ocean, the balance will tip to rapid ice loss, bringing multiple positive feedbacks into play and causing cataclysmic ice sheet disintegration. The Earth's history suggests that with warming of 2-3°C the new equilibrium sea level will include not only most of the ice from Greenland and West Antarctica, but a portion of East Antarctica, raising sea level of the order of 25 meters (80 feet).

Contrary to lethargic ice sheet models, real world data suggest substantial ice sheet and sea level change in centuries, not millennia. The century time scale offers little consolation to coastal dwellers, because they will be faced with irregular incursions associated with storms and with continually rebuilding above a transient water level.

The grim "Business-as-Usual" climate change is avoided in an Alternative Scenario in which growth of greenhouse gas emissions is slowed in the first quarter of this century, primarily via concerted improvements in energy efficiency and a parallel reduction of non-CO_2 climate forcings, and then reduced via advanced energy technologies that yield a cleaner atmosphere as well as a stable climate. The required actions make practical sense and have other benefits, but they will not happen without strong policy leadership and international cooperation. Action must be prompt, otherwise CO_2-producing infrastructure that may be built within a decade will make it impractical to keep further global warming under 1°C.

There is little merit in casting blame for inaction, unless it helps point toward a solution. It seems to me that special interests have been a roadblock wielding undue influence over policymakers. The special interests seek to maintain short-term profits with little regard to either the long-term impact on the planet that will be inherited by our children and grandchildren or the long-term economic well-being of our country.

The public, if well-informed, has the ability to override the influence of special interests, and the public has shown that they feel a stewardship toward the Earth and all of its inhabitants. Scientists can play a useful role if they help communicate the climate change story to the public in a credible understandable fashion.

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Can We Still Avoid Dangerous Human-Made Climate Change?

A. Recent Global Temperature Change and Fluctuations

Chart 1. Can We Still Avoid Dangerous Human-Made Climate Change?

I begin with two caveats: (1) I am speaking as a scientist based on my thirty-some years of experience in NASA, but I am not speaking for the agency or the government; these are my personal scientific opinions. (2) I do not attempt to define policy, which is up to the people and their elected representatives, and I don't criticize policies. The climate science has policy relevance, but I let the facts speak for themselves about consequences for policy-makers.

I intend to show that the answer to the question "Can we still avoid dangerous human-made climate change" is yes, we could, but we are not now on a path to do that, and if we do not begin actions to get on a different path within the next several years we will pass a point of no return, beyond which it is impossible to avoid climate change with far ranging undesirable consequences. Why we are not taking actions to avoid climate change relates to the topic of this conference, which I will address in the latter part of my talk. But I will spend most of my time on the climate science, because its communication is important, and may have been lost in recent hullabaloo.

Chart 2. Land-Ocean Temperature Index.
Global mean surface temperature change based on surface air measurements over land and SSTs over ocean.
Sources: Hansen *et al.*, *JGR*, **106**, 23947, 2001; Reynolds and Smith, *J. Climate*, **7**, 1994; Rayner et al., *JGR*, **108**, 2003.

The Earth is getting warmer. Rapid warming in the past three decades coincides with the time in which greenhouse gas climate forcing became much larger than other climate forcings.

Global warming in just the past 30 years is about six tenths of a degree Celsius, about 1 degree Fahrenheit.

Chart 3. Monthly Surface Temperature Anomalies (°C).
Anomalies of surface temperature index in recent months relative to 1951-1980 base period.
Sources: Hansen *et al.*, *JGR*, **106**, 23947, 2001; Reynolds and Smith, *J. Climate*, **7**, 1994; Rayner et al., *JGR*, **108**, 2003.

But it is important to remind people that one degree Fahrenheit, or one and one-half degrees, which is the global warming over the past century, is much smaller than day-to-day weather fluctuations or even month-to-month changes in the average temperature. This is a map of monthly temperature anomalies for the past year (in degrees Celsius, Fahrenheit anomalies are approximately twice as large). In the Midwest January was the warmest on record, about 5 Celsius above normal, but Europe and Western Asia were abnormally cold. Fluctuations are normal, although this case was unusual, as you can see by comparison with previous months. You can also see that warm anomalies dominate over cool anomalies. And the notion that European cold weather is due to a slowdown of the Atlantic circulation is a red herring; the Atlantic Ocean is warmer than normal.

Chart 4. 2001-2005 Mean Surface Temperature Anomaly (°C).
Mean surface temperature anomaly for the past five years.
Sources: Hansen *et al.*, *JGR*, **106**, 23947, 2001; Reynolds and Smith, *J. Climate*, **7**, 1994; Rayner et al., *JGR*, **108**, 2003.

However, if we look at the average surface temperature anomaly for the past five years, we see that it was warmer than climatology, the 1951-1980 mean, almost everywhere. Warming occurs over the ocean as well as land, and the largest warming is in remote regions. This is a real global warming, not an artifact of thermometers being located close to urban centers.

B. Climate Sensitivity

Chart 5. Antarctic Time Series for CO_2, CH_4 and Temperature
CO_2, CH_4 and temperature records from Antarctic ice cores.
Sources: Petit *et al.*, *Nature*, **399**, 429, 1999 ; Vimeux *et al.*, *Earth Planet. Sci. Lett.*, **203**, 829, 2002.

Let's turn to climate sensitivity. The most precise knowledge about climate sensitivity comes not from climate models per se, but from empirical information on climate change interpreted with the aid of climate models.

These are records of atmospheric carbon dioxide, methane and temperature for the past 400,000 years extracted from Antarctic ice cores. The temperature difference between the warmest, interglacial, periods, and the depths of the ice ages is about 10 degrees Celsius in Antarctica, about 5 degrees on global average, and about 3 degrees over equatorial oceans. We can evaluate climate sensitivity by comparing the present interglacial, the Holocene, the warm period that has existed for about 10,000 years, with the ice age that peaked 20,000 years ago.

Chart 6. Ice Age Climate Forcings
Ice age forcings imply an equilibrium global climate sensitivity ¾°C per W/m^2.
Source: Hansen et al., *Natl. Geogr. Res. & Explor.*, **9**, 141, 1993.

We know the change of surface conditions on the planet quite well. An ice sheet covered Canada and parts of the United States during the ice age. The brighter surface reflected more sunlight away, so there was less heating of the Earth, which reduced climate forcing by about 3 ½ Watts per square meter. The atmosphere was also different with less greenhouse gases during the ice age. The total forcing of about 6½ W/m^2 maintained a global temperature difference of 5 degrees, implying a climate sensitivity of ¾ ± ¼ ºC for each Watt per square meter of forcing.

This is about the same climate sensitivity that climate models yield. Nevertheless, you might choose to argue that we derived this climate sensitivity from just two points in time, and it may not be general. Well, we can now test that, because detailed sea level data is available for the past 400,000 years.

Chart 7. Sea Level from Red Sea Analysis of Siddall et al.
Global sea level extracted, via a hydraulic model, from an oxygen isotope record for the Red Sea over the past 470 thousand years (concatenates Siddall's MD921017, Byrd, and Glacial Recovery data sets; AMS radiocarbon dating).
Source: Siddall et al., *Nature*, **423**, 853-858, 2003.

Sea level changes by about 100 meters between ice ages and interglacial periods. For reasonable assumptions about the shape of ice sheets, we can approximate the area covered by ice, and thus the ice sheet climate forcing, as being proportional to the sea level change to the 2/3 power. Given the ice sheet forcing of 3½ W/m^2 20,000 years ago, when sea level was about 110 meters lower, we obtain an ice sheet forcing for the entire 400,000 year period.

Chart 8. Paleoclimate Forcings
Ice sheet forcing ~ $(\text{sea level})^{2/3}$
GHGs = $CO_2 + CH_4 + N_2O$ (=0.15 forcing of $CO_2 + CH_4$)

As shown in a previous graph, we know the changes of atmospheric gases over the past 400,000 years very accurately, so we can calculate the greenhouse gas climate forcing. The ice sheet and greenhouse gas forcings are comparable in magnitude. Dating errors in comparing the radiocarbon-dated sea level with ice core gases can be as much as several thousand years.

The planet must be in radiation balance on these millennial time scales. If the planet were out of balance by even one Watt per square meter for a thousand years, it would melt all the ice on the planet or raise the ocean temperature an implausible amount. So we can just multiply the sum of these two forcings by climate sensitivity, ¾ of a degree per W/m^2, to obtain an estimate of the expected global temperature change, which is the blue curve in Figure 9.

Chart 9. Paleoclimate Temperature Change
Observations = Vostok □T/2. Calculated temperature = Forcing x 0.75°C/W/m^2

Observed temperature change is estimated here as one-half of the Antarctic temperature change. The agreement of observed temperature with that calculated from known forcings, without making time scale adjustments that could improve the fit, has important implications, over and above the conclusion that climate sensitivity ¾°C per Watt fits the entire record. These implications can be understood with the help of two more pieces of information.

Chart 10. CO_2, CH_4 and Temperature.
CO_2, CH_4 and estimated global temperature (Antarctic □T/2 in ice core era). 0 = 1880-1899 mean.
Source: Hansen, *Clim. Change*, **68**, 269, 2005.

First, we note that although the temperature, carbon dioxide and methane changes are reasonably congruent, when we look at them carefully, we find that the temperature changes usually lead the gas changes by about a thousand years or so. Second, we note that the greenhouse gas changes that humans have introduced in the past century are far outside the range that has existed for hundreds of thousands of years, and they will remain so for centuries because of the long lifetime of some of these gases. Also, in the past century, for which I have greatly expanded the time scale on the right, the planet is not in energy balance with space, unlike the earlier part of the graph. In the present century the gases were added so fast that the planet has not yet had time to fully respond.

Chart 11. Implications of Paleo Forcings and Response

It follows that feedbacks – or you can describe greenhouse gas changes and ice sheet changes as indirect forcings, if you like, indirect forcings brought about by Earth orbital changes and other factors, but these feedbacks or indirect forcings operate in response to temperature change. And as I showed, these "feedback" mechanisms cause almost the entire paleo temperature change. Therefore climate change on these time scales is very sensitive to even small forcings. The instigators of climate change, the pacemakers, include especially Earth orbital variations, which change the distribution and seasonality of sunlight on the planet, but also any other small forcings, and chaos. Finally, because of the overwhelming amount of human-made greenhouse gases, another "ice age" cannot occur unless humans become extinct. Even then, it would require thousands of years. Humans now control global climate, for better or worse.

C. Climate Change in the Industrial Era

Chart 12. Effective Climate Forcings (W/m^2): 1750-2000.
Climate forcing agents in the industrial era. "Effective" forcing accounts for "efficacy" of the forcing mechanism.
Source: Hansen *et al.*, *JGR*, **110**, D18104, 2005.

Now let's turn to the industrial era. Humans have introduced an array of climate forcings, that is, alterations of the planet's energy budget that tend to change the Earth's temperature. Forcings by greenhouse gases are known accurately, within about 15%. Forcing by aerosols, that is soot and other fine particles in the air, is not known accurately; the uncertainty is at least 50%. In recent decades the growth rate of aerosols has slowed, as some countries have tried to reduce particulate air pollution.

Chart 13. Global Climate Forcings and Surface Temperature Change.
(A) Forcings used to drive climate simulations. (B) Simulated and observed surface temperature change.
Source: Hansen *et al.*, *Science*, **308**, 1431, 2005.

Our best estimate for these forcings as a function of time includes a sporadic cooling effect of volcanic aerosols, which is known quite well. Solar forcing is believed to have a small positive trend, but it is rather uncertain. The net forcing is about 1.85 W/m^2 in 2003 relative to 1880.

These forcings, when inserted in our global climate model, yield global warming over the past century in remarkably good agreement with observations, as shown in the lower graph. We could have achieved comparable agreement if we had used a larger forcing in a model with smaller climate sensitivity, or conversely. However, the sensitivity of our model is consistent with that indicated by paleoclimate data.

Chart 14. Planetary Energy Imbalance and Ocean Heat Content.
(A) Net radiation at top of atmosphere in climate simulations. (B) Ocean heat gain in top 750 m of world ocean.
Source: Hansen *et al.*, *Science*, **308**, 1431, 2005.

An important result of the climate simulations is that the planet must now be out of energy balance, if the forcings and model sensitivity are approximately correct. The energy imbalance is a direct result of greenhouse gases blocking outgoing radiation, so it is a fundamental test and confirmation of the greenhouse effect.

Chart 15. Consistency Check and Implications.
Earth's energy imbalance implies further warming and sea level rise are "in the pipeline".
Source: Hansen *et al.*, *Science*, **308**, 1431, 2005.

Of the 1.85 W/m^2 net forcing in 2003 relative to 1880, 1 W/m^2 has been used to produce the observed 0.7°C global warming. The remaining 0.85 W/m^2 remains to be responded to, which means there is about one-half degree Celsius or one degree Fahrenheit global warming still in the pipeline. The imbalance also confirms the long lag time of the climate system, which is a practical problem, because it means that, once we decide on the level of global warming that is dangerous, we must take anticipatory actions well before we get there.

D. Future Climate Change

Chart 16. United Nations Framework Convention on Climate Change.

Let's look at future climate. 15 years ago all nations, including the United States, agreed to the Framework Convention on Climate Change. The goal: to stabilize greenhouse gas emissions at a level that prevents dangerous human interference with climate. But what level of global warming constitutes dangerous interference?

I will argue that we are near a tipping point, a point of no return, beyond which the built in momentum and feedbacks will carry us to levels of climate change with staggering consequences for humanity and all of the residents of this planet.

Chart 17. 21st Century Global Warming.
Climate simulations for IPCC 2007 report.
Source: Hansen et al., *J. Geophys. Res., submitted.*

We tested the ability of our climate model to simulate past climate change. Now let's extend simulations into the future for different scenarios. IPCC scenarios A2 and A1B have a growth rate for CO_2 emissions of about 2% per year over the next 50 years, similar to the actual growth rate of the past 10 years. The Alternative Scenario, in contrast, assumes slowly declining emissions, so that added CO_2 forcing is about 1 W/m^2 in 50 years and 1.5 W/m^2 over 100 years. That forcing, and climate sensitivity consistent with paleoclimate data, yield additional warming beyond year 2000 that peaks in the early 22nd century at less than 1°C. In the Business-As-Usual scenarios, added warming is more than 2°C and still rising rapidly at the end of century.

Chart 18. "Dangerous" Climate Change: Physical Climate System Approach
Outline of topics to be covered.

How much more "dangerous" is 2-3°C global warming, as opposed to less than 1°C? The big global issue, in my opinion, is sea level. It is helpful to break the sea level discussion into two parts: the equilibrium change for a given magnitude of global warming, and the question of how long it takes the ice sheets to respond to global warming.

In the past 400,000 years the warmest interglacial periods were about 1°C or so warmer than today, and perhaps in one or two cases sea level was higher than today, possibly as much as about 5 meters. In order to find a temperature 2½ or 3°C warmer than today, we must go back to the Middle Pliocene, 3 million years ago, when sea level was about 25 meters (80 feet) higher than today. Along the East Coast there is geological feature called the Orangeburg Scarf, which was the coast-line 3 million years ago. It's typically 100 km inland now, about 25-35m above sea level, and Florida was under water.

The principal uncertainty is how long it requires for ice sheets to respond to warming. There is now much evidence indicating that ice sheets respond substantially to warming in centuries. In one period during the last deglaciation 14,000 years ago, sea level went up 20 meters in 400 years, that is an average of one meter every 20 years. Rapid sea level changes of 10 meters or more have occurred many times in the past.

Chart 19. Increasing Melt Area on Greenland.
Satellite-era record melt of 2002 was exceeded in 2005.
Source: Waleed Abdalati, Goddard Space Flight Center

Ice sheet disintegration can occur rapidly, because it is a wet process. The area on Greenland with summer melt fluctuates with the weather, but it has increased a lot in recent years. The summer of 2005 broke the prior record for melt area.

Chart 20. Jakobshavn Ice Stream in Greenland.
Discharge from major Greenland ice streams is accelerating markedly.
Source: Konrad Steffen, Univ. Colorado

Meltwater descends through crevasses and lubricates the base of the ice sheet. This is the largest ice stream on Greenland, which has doubled its speed in recent years. Other major ice streams on Greenland have also sped up. With additional global warming of 2-3°C, summer melt would cover most of the ice sheet, and it is inconceivable to me that either Greenland or West Antarctica would survive. Indeed, the history of the Earth indicates that they would not, and eventually part of East Antarctica would go with them.

Sea level will increase slowly at first, as losses on the fringes of the ice sheets due to accelerating ice streams are nearly balanced by increased snowfall in the ice sheet interiors. But as the ice is softened and lubricated by melt-water and as buttressing ice shelves disappear due to a warming ocean, a point of no return will be reached when multiple positive feedbacks take over and cause cataclysmic ice sheet disintegration. And contrary to some old lethargic ice sheet models, real world data imply substantial sea level change in centuries, not millennia. The century time scale is probably the worst case for coastal dwellers, because the damage occurs irregularly in conjunction with storms, so they would be faced with repeatedly rebuilding above a transient water level.

Chart 21. Regional Climate Change.

Outline for discussion of global warming effects on regional climate.

Let's turn to regional climate change, for which I will use a simple argument to make a general statement, and then look at some specific cases.

Chart 22. 2000-2100 Temperature Change in IPCC and Alternative Scenarios.

** is interannual standard deviation of observed seasonal mean temperature for period 1900-2000.**

Source: Hansen et al., *J. Geophys. Res., submitted.*

On the left, calculated with our climate model, is the change of Jun-Jul-Aug temperature by the end of the present century for two IPCC scenarios and the Alternative Scenario. The model has sensitivity consistent with paleoclimate and climate change of the past century, indeed, these are extensions of the runs that fit observed climate well.

On the right is the ratio of the mean warming to the local standard deviation of seasonal mean temperature in the 20^{th} century. The standard deviation includes the effect of both year-to-year variations and long-term change, i.e., it is a measure of the total variation in the past century. I submit that changes in the mean by 5-10 standard deviations in the Business-as-Usual scenarios are prima facie evidence of dangerous change. 5 to 10 standard deviations would mean that the environment and its inhabitants would face average local conditions that they had never experienced, even in the most extreme years. People can adjust to that, but the ecology will have a harder time

Chart 23. Arctic Climate Impact Assessment.

Credits: Claire Parkinson and Robert Taylor.

The Arctic provides a good specific example of regional climate change. Like sea level, it has a potential tipping point, because of positive feedback. As ice melts the ocean absorbs more sunlight and becomes warmer. It is not a runaway feedback or instability, but it does mean that a moderate increase in forcings could melt all of the summer ice, destroying the habitat of many species and the way of life of indigenous peoples.

We are getting dangerously close to the tipping point for the Arctic, as summer sea ice has already decreased about 25% since the late 1970s. At this point it is still possible to save the Arctic, because even though there will surely be increased CO_2 forcing this century, there are other facings that are very effective in the Arctic, specifically methane, tropospheric ozone, and black soot. A focused effort to reduce these pollutants might suffice to stabilize Arctic climate, provided that the CO_2 growth rate decelerated as in the Alternative Scenario.

Chart 24. Tropical Storms.

I want to mention tropical storms, a topic that I dropped from my AGU talk because of time constraints, because it is especially relevant to this conference. Our climate simulations, which do a good job of matching observed global climate change, yield a human-made ocean surface warming in the region of hurricane formation that is equal to a large fraction of the observed warming there. So the categorical contention of the NOAA National Hurricane Center that recent hurricane intensification is due to a natural cycle of Atlantic Ocean temperature, and has nothing to do with global warming, is irrational. How could a hurricane distinguish between a natural and greenhouse gas warming? It is conceivable, but it would require an explanation that has not been proffered. I suggest that greenhouse gases may be responsible for a substantial fraction of the ocean warming that fuels stronger hurricanes.

I mention this because NOAA took an official position that global warming was not the cause of hurricane intensification, and as the public was glued to their television listening to reports from the Hurricane Center, that is the main message the public received. The topic is a complex one that the scientific community is working on, but it seems that the public, by fiat, received biased information. NOAA scientists were told not to dispute the Hurricane Center conclusion in public. I am not certain whether that is legal or not. Perhaps, by declaring the conclusion to be "policy", NOAA scientists can be prohibited from questioning it in public.

Chart 25. Feynman Quotation.

What I can say is that an official government position restricting discussion of a scientific matter flies in the face of the scientific method. You will not be successful in science unless you are able to explain and discuss what is bad and what is good about any theory. More broadly, I do not see how any decision-making can be successful, if there is not freedom to question.

There has been publicity lately about restrictions on NASA communications with the media. NASA is working on that and I have high hopes that NASA will fix its problem and be a model for other agencies. We will see. But I am told by NOAA colleagues that their conditions are much worse than those in NASA. A NOAA scientist cannot speak with a reporter unless there is a "listener" on the line with him or her. It seems more like the old Soviet Union than the United States. The claim is that the "listener" is there to protect the NOAA scientist. If you buy that one, please see me at the break; there is a bridge down the street that I would like to sell to you.*

**In my oral presentation I regrettably used the phrase "like Nazi Germany or the Soviet Union". Upon reflection I prefer the phrase "like the old Soviet Union", which is not as laden with emotions and possible misinterpretation. Also, I note that not all NOAA conversations with reporters are accompanied by a "listener". However, that makes NOAA efforts to include a "listener" during discussion of "sensitive" topics such as global warming all the more reprehensible. The validity of my assertion is supported by a 16 February 2006 Wall Street Journal article by Antonio Regalado and Jim Carlton.*

There is a good rationale for preventing scientists from intruding in policy-making. The converse is also true. Policy should not intrude in science, or it will destroy the quality of the science and diminish the value of the science to the public.

The ultimate policy-maker is the public. Unless the public is provided with unfiltered scientific information that accurately reflects the views of the scientific community, policy-making is likely to suffer.

In summary, with regard to regional climate: as with global climate and sea level, Business-as-Usual scenarios by the end of the century produce basically another planet. How else can you describe climate change in which the Arctic becomes an open lake in the summer and fall, and most land areas on Earth experience mean warming this century that is 5-10 times larger than the standard deviation of the past century?

G. Greenhouse Gas Scenarios and Real World Trends

Back to the question: can we still avoid dangerous human-made climate change? That would require avoiding Business-as-Usual 2-3°C global warming. We must keep additional global warming, beyond that of 2000, under 1°C. That is possible, but it requires two things. First, we must get CO_2 emissions to flatten out and decline substantially before mid-century. Second we must obtain an absolute decrease of non-CO_2 forcings. CO_2 is the toughest problem.

Chart 26. Annual CO_2 Growth (ppm/year).
Growth rate of atmospheric CO_2 (ppm/year). Source: Hansen and Sato, *PNAS*, **101**, 16109, 2004.

The observed growth of CO_2 in the air, the blue curve in Chart 26, fluctuates a lot, but it is now headed in the direction of IPCC Business-as-Usual. This becomes clearer, if we note that the CO_2 growth rate, and thus CO_2 emissions, would need to decline moderately this half-century to achieve the Alternative Scenario, while in reality (Chart 27) global CO_2 emissions are increasing rapidly, about 2% per year in the past decade. Is continued growth of this sort inevitable, or is there a feasible course that would achieve the Alternative Scenario?

Chart 27. Global Fossil Fuel CO_2 Emissions.
Global fossil fuel CO_2 emissions divided according to country or region of emissions. Source: Hansen and Sato, *PNAS*, **101**, 16109, 2004.

I remind you that I do not specify policy. What I do is look at current trends and estimate the changes needed to bring the climate forcing growth rate down to that of the Alternative Scenario.

On the long run, satisfying energy needs while decreasing CO_2 emissions will require development of renewable energies, sequestration of CO_2 produced at power plants, and likely a new generation of nuclear power. However, these future technologies do not substantially alter near-term emissions. Near-term emissions are important, because continued growth of CO_2 emissions at 2% per year would yield a 22% increase of emission rate in 10 years and a 35% increase in 15 years. The long life of atmospheric CO_2 and the energy-producing infrastructure would make attainment of the Alternative Scenario impractical.

Specifically, the two major sources of CO_2 emissions that would need to be flattened out this decade are vehicles, which is the fastest growing source, and power plants, which has the longest-lived infrastructure, especially coal-burning power plants without sequestration. The best prospects for achieving the needed reductions in the near to middle term are in energy efficiency. To achieve the Alternative Scenario, it would be essential for the United States, as a technology leader and as the largest producer of CO_2 in the world, to take a leadership role.

Chart 28. U.S. Auto & Light Truck CO_2 Emissions.
"Moderate Action" is NRC "Path 1.5" by 2015 and "Path 2.5" by 2030.
Source: *On the Road to Climate Stability*, Hansen, J., D. Cain and R. Schmunk,, *to be submitted.*

For vehicles, efficiency provides the potential to achieve the Alternative Scenario track, even though the number of vehicles on the road increases every year. For example, the graph in Chart 28 uses the moderate recommendations of the National Research Council, which have a vehicle efficiency improvement of 30%, based on existing technology. The illustrated emission scenario gives the automakers ample time to phase in new technology. However, for it to happen would require that auto-makers stop opposing efficiency requirements in court and stop pressuring lawmakers to oppose efficiency.

The accrued benefit in 35 years, of just this moderate action, even without more capable future technologies, is a savings of oil equal to more than seven times the amount of oil that the U.S. Geological Survey estimates to be available in the Arctic National Wildlife Refuge.

Chart 29. Oil Savings (barrels/day, $B/year).
United States annual savings (at $50/barrel, today's dollars) in 2030 for alternative automobile efficiency improvements.
Source: *On the Road to Climate Stability*, Hansen, J., D. Cain and R. Schmunk,, *to be submitted.*

The savings of this moderate action, at $50 per barrel of oil, is about $100B per year. These savings increase each year, even without additional efficiency improvements.

Chart 30. 2004 Portions of CO_2 Emissions.
Fossil fuel CO_2 emissions by source country in 2004.
Source: Hansen et al., *J. Geophys. Res., submitted.*

Climate is a global problem and CO_2 emissions are a global problem. The U.S. is the largest emitter, but China and India are growing more rapidly. But they have been growing rapidly the past decade, and the 2%/year growth of global emissions could be halted with sensible actions. China and India, overall, are even less efficient than the U.S. and they will probably suffer more from changing climate. There will be a tremendous market for improved efficiency, which we could pursue much more vigorously, for our own good as well as for the planet's.

Chart 31. Workshop at East-West Center.
Technical cooperation offers large mutual benefits to developed and developing countries.
Source: *Air Pollution as Climate Forcing,* workshop reports, http://www.giss.nasa.gov/meetings/pollution02/ and 2005/.

The goal of keeping further global warming under 1°C requires two things: first, flattening out and then decreasing the rate of growth of CO_2 emissions, and second an absolute decrease in emissions of non-CO_2 climate forcings, particularly methane and carbon monoxide, and therefore tropospheric ozone, and black carbon (soot) aerosols. There are multiple reasons to do this, with benefits for developed and developing countries, and for the planet and future generations. But these are not things that will simply happen because they make sense. There has to be leadership.

Chart 32. Summary: Is There Still Time? Yes, but:

So, in summary, is there still time to avoid dangerous human-made interference with climate? I believe the evidence shows with reasonable clarity that the level of additional global warming that would put us into dangerous territory is about 1°C, not 2 or 3°C. We will need to refine our estimate as more data comes in, but I am very confident of this assertion.

Yes, it is technically possible to avoid the grim "Business-as-Usual" climate change, to follow an Alternative Scenario in which growth of greenhouse gas emissions is slowed in the first quarter of this century, primarily via concerted improvements in energy efficiency and a parallel reduction of non-CO_2 climate forcings, and then reduced via advanced energy technologies that yield a cleaner atmosphere as well as a stable climate. The required actions make practical sense and have other benefits, but they will not happen without strong policy leadership and international cooperation. Action must be prompt, otherwise CO_2-producing infrastructure that may be built within a decade will make it impractical to keep further global warming under 1°C. I refer especially to the large number of coal-fired power plants that China, the United States, and India are planning to build without CO_2 sequestration.

So, if the Alternative Scenario is practical, has multiple benefits, and makes good common sense, why are we not doing it?

There is little merit in casting blame for inaction, unless it helps point toward a solution. It seems to me that special interests have been a roadblock wielding undue influence over policymakers. The special interests seek to maintain short-term profits with little regard to either the long-term impact on the planet that will be inherited by our children and grandchildren or the long-term economic well-being of our country.

The public, if well-informed, has the ability to override the influence of special interests, and the public has shown that they feel a stewardship toward the Earth and all of its inhabitants. Scientists can play a useful role if they help communicate the climate change story to the public in a credible, understandable fashion.

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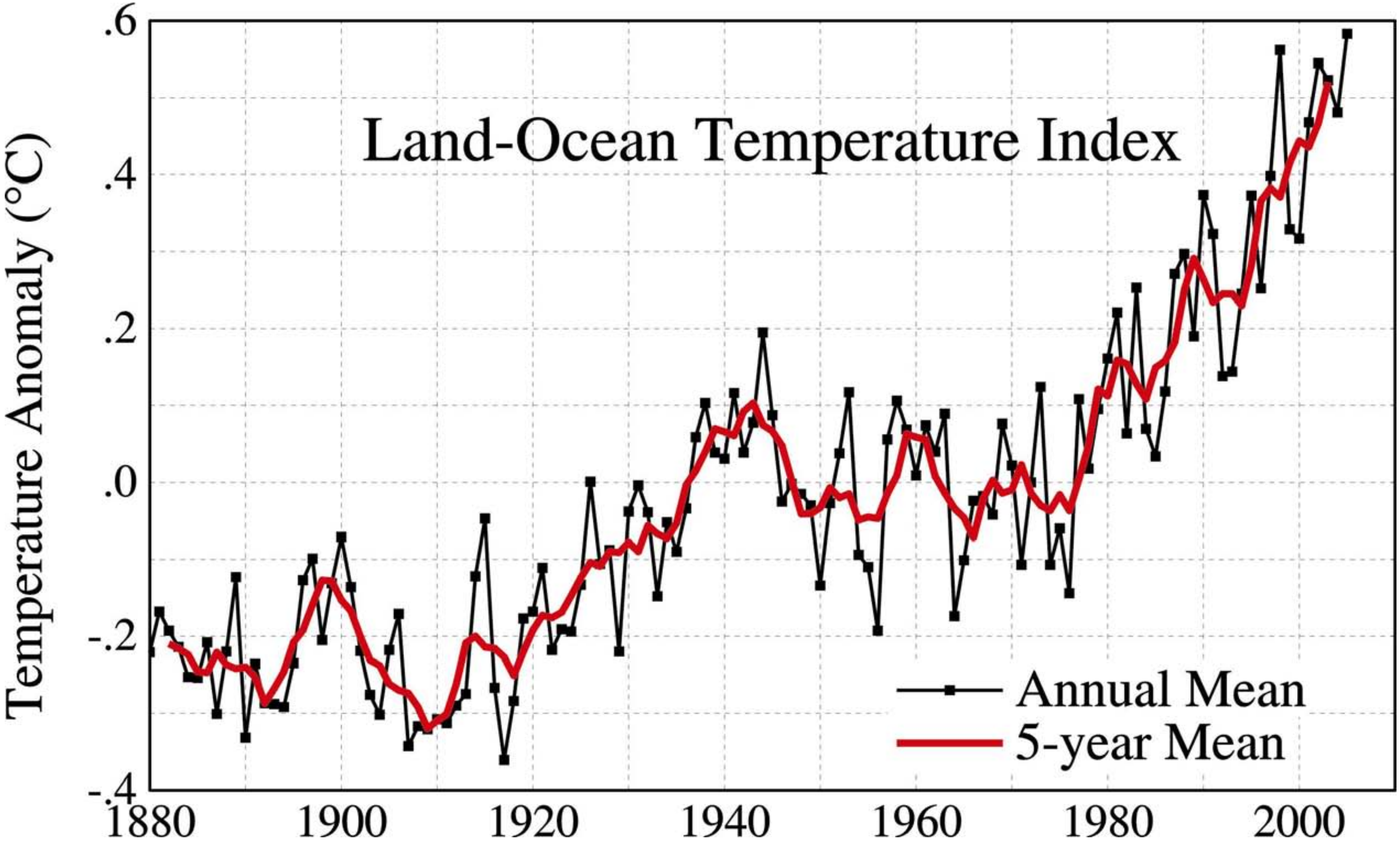
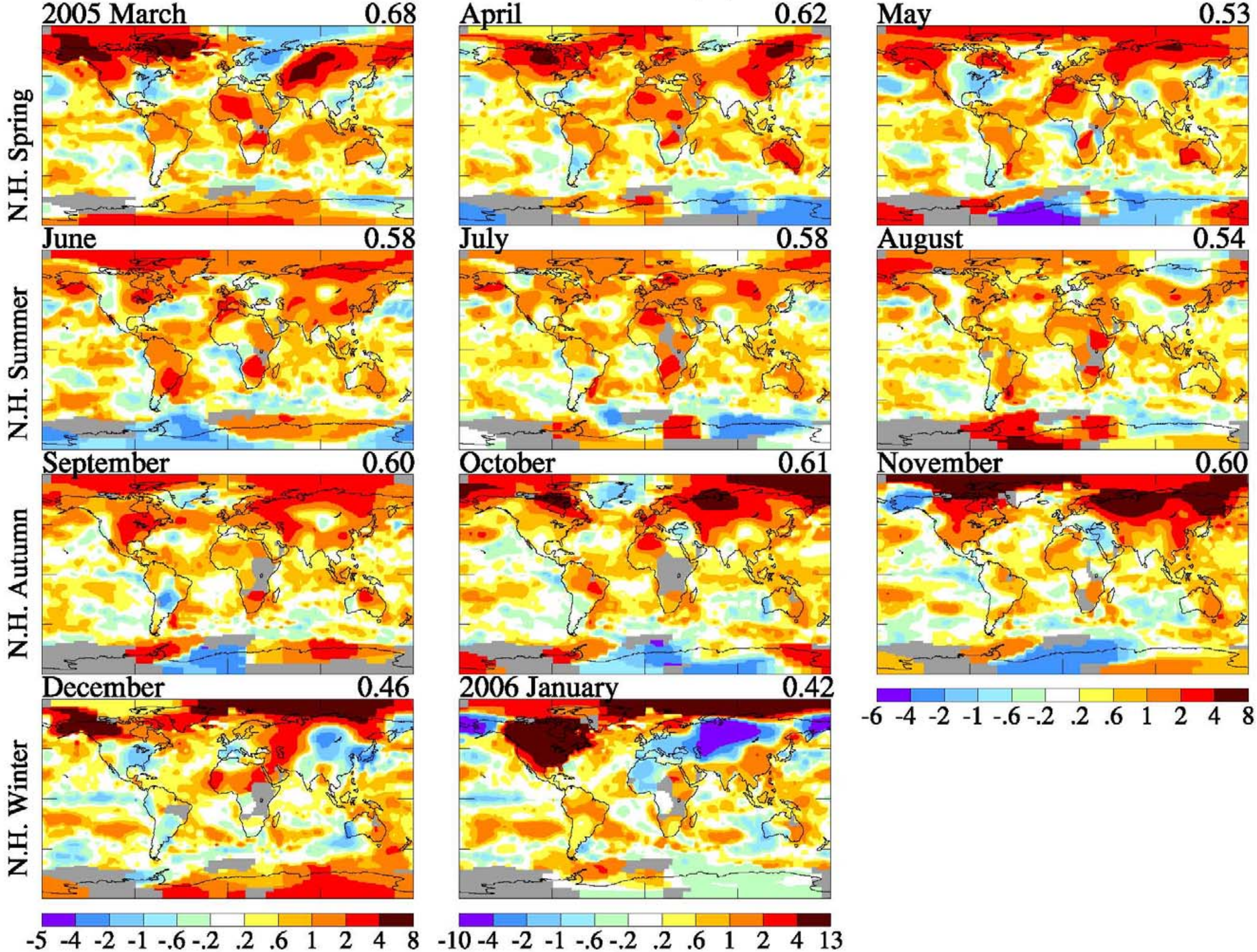
Presentation on 10 February 2006 by James E. Hansen
New School University, New York



Global mean surface temperature change based on surface air measurements over land and SSTs over ocean

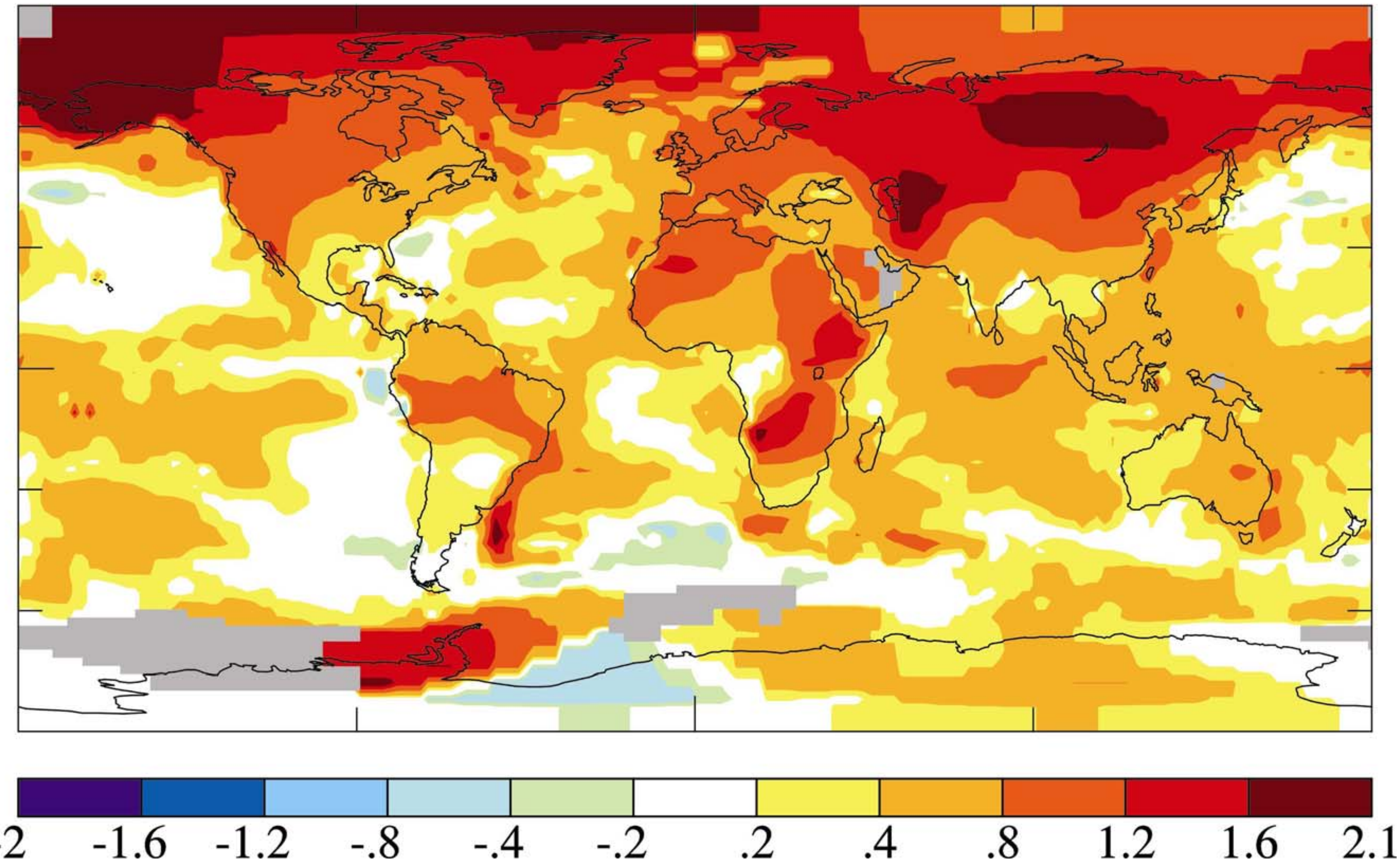
Source: Update of Hansen et al., *JGR,* **106**, 23947, 2001; Reynolds and Smith, *J. Climate,* **7**, 1994; Rayner et al., *JGR,* **108**, 2003.

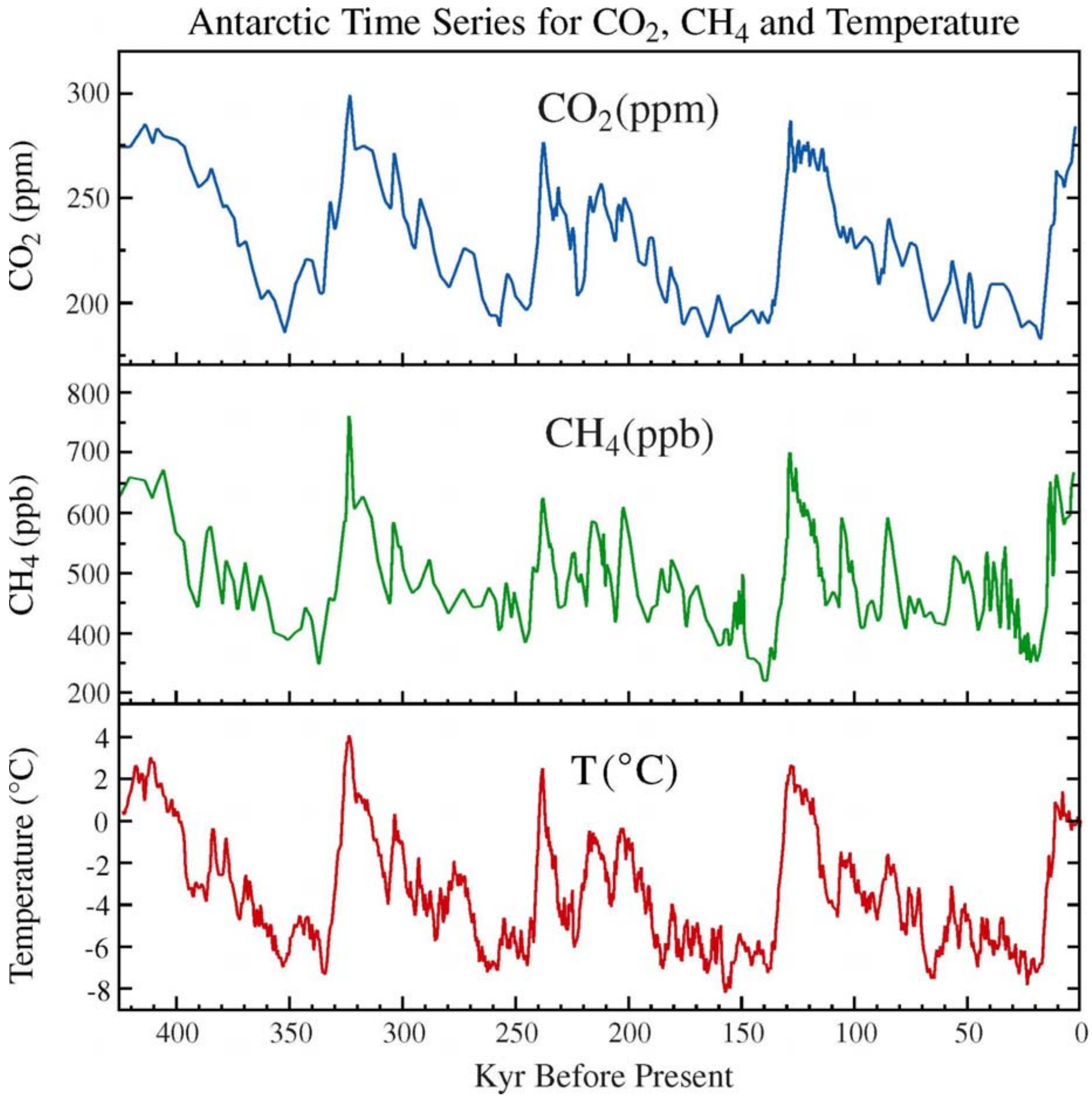
Surface Temperature Anomalies (°C) [Base Period 1951-80]



2001-2005 Mean Surface Temperature Anomaly (°C)

Base Period = 1951-1980 Global Mean = 0.53

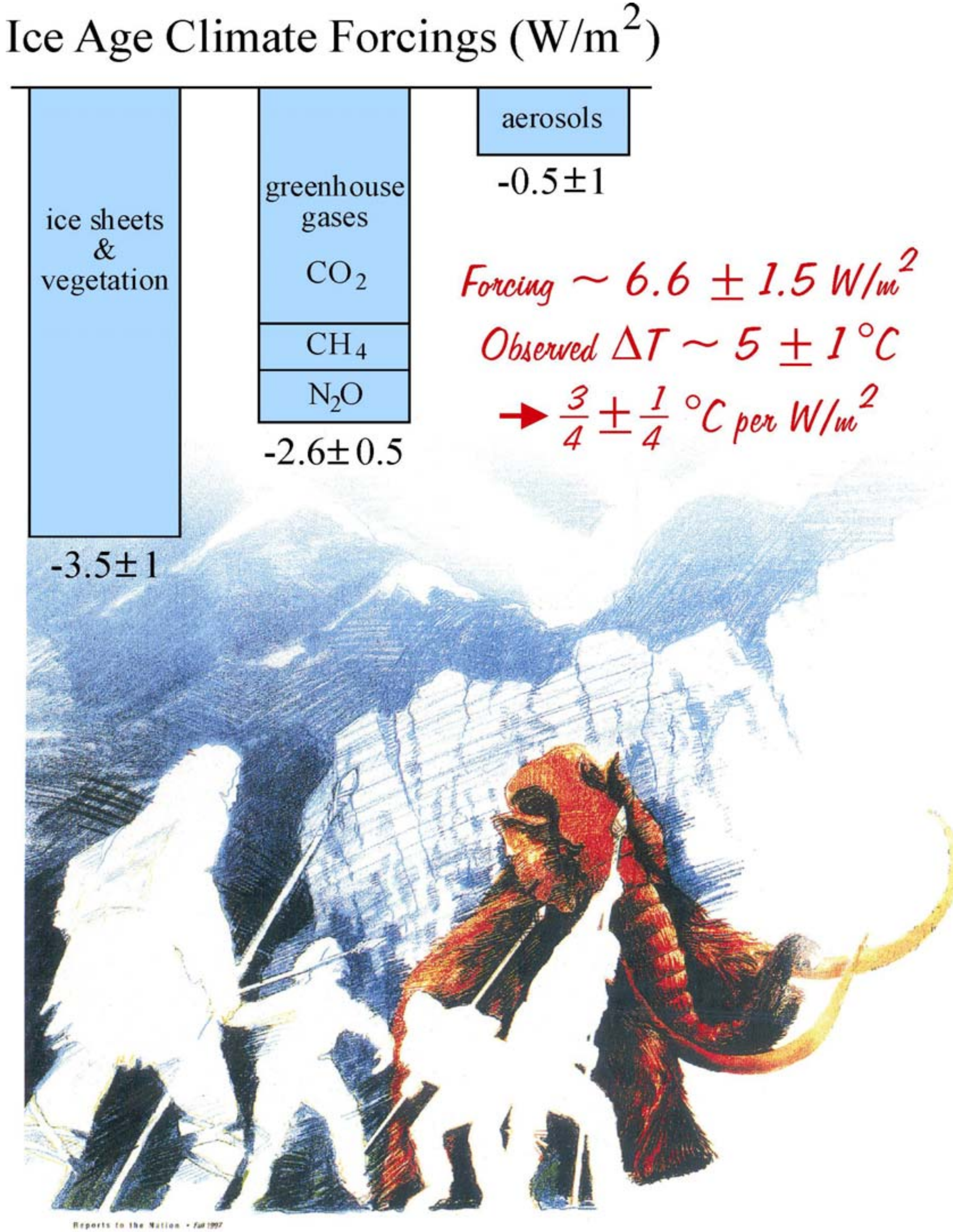




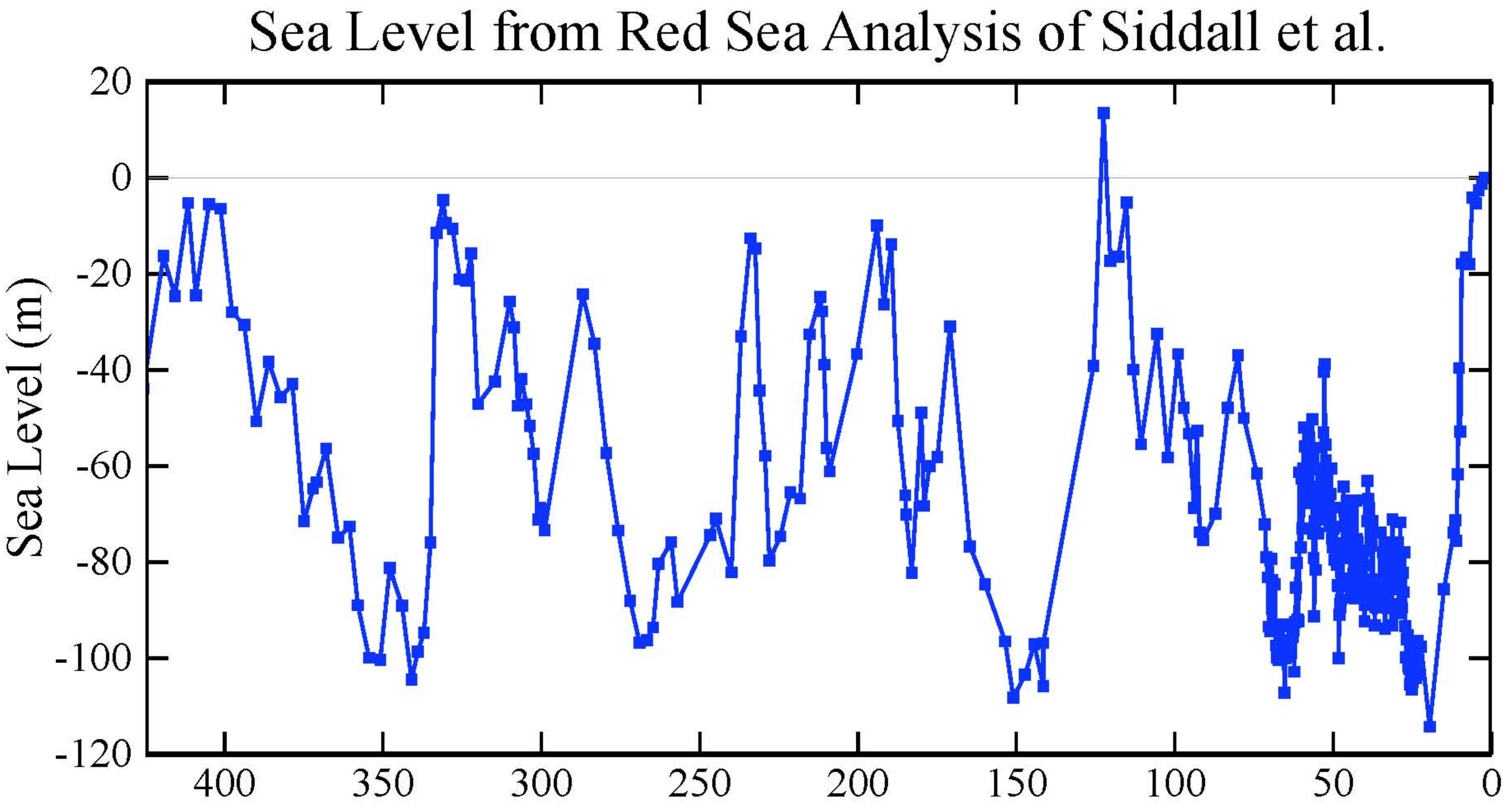
CO_2, CH_4 and temperature records from Antarctic ice core data

Source: Vimeux, F., K.M. Cuffey, and Jouzel, J., 2002, "New insights into Southern Hemisphere temperature changes from Vostok ice cores using deuterium excess correction", *Earth and Planetary Science Letters*, **203**, 829-843.

Ice Age Forcings Imply Global Climate Sensitivity ~ ¾°C per W/m^2.

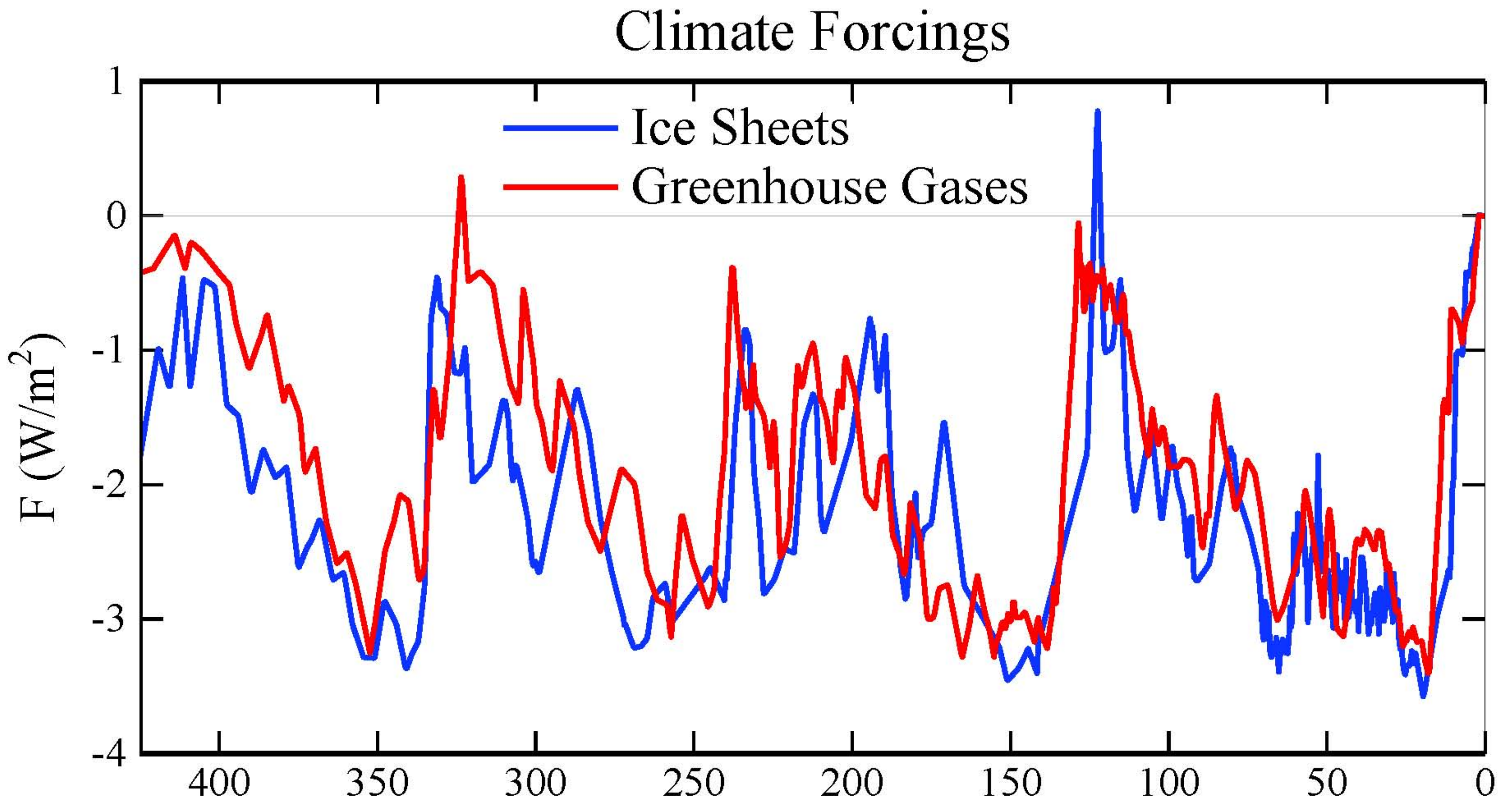


Source: Hansen et al., *Natl. Geogr. Res. & Explor.,* **9***,* 141, 1993.



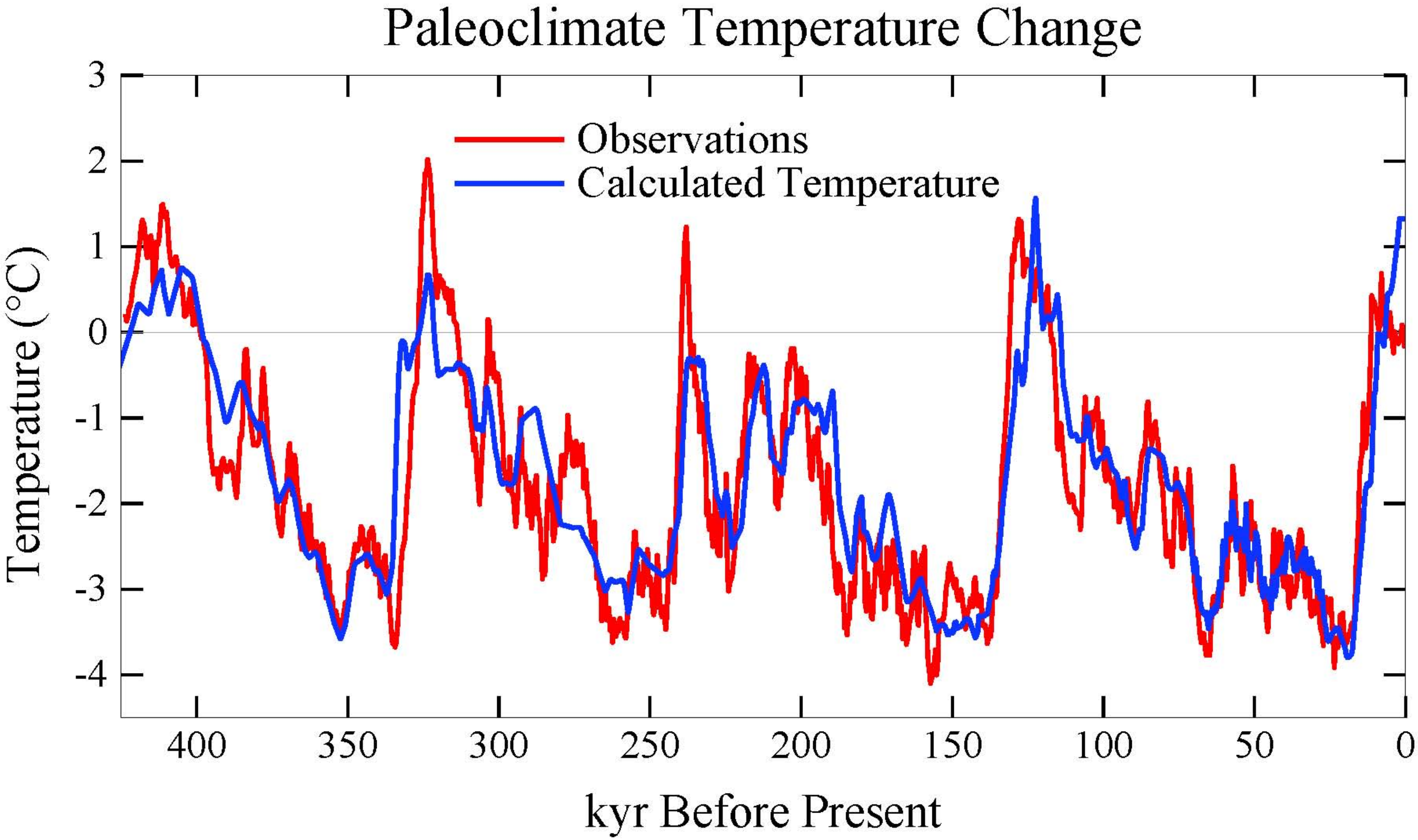
Global sea level extracted, via a hydraulic model, from an oxygen isotope record for the Red Sea over the past 470 kyr (concatenates Siddall's MD921017, Byrd, & Glacial Recovery data sets; AMS radiocarbon dating).

Source: Siddall et al., *Nature*, **423**, 853-858, 2003.



Ice sheet forcing ≅ (sea level)$^{2/3}$

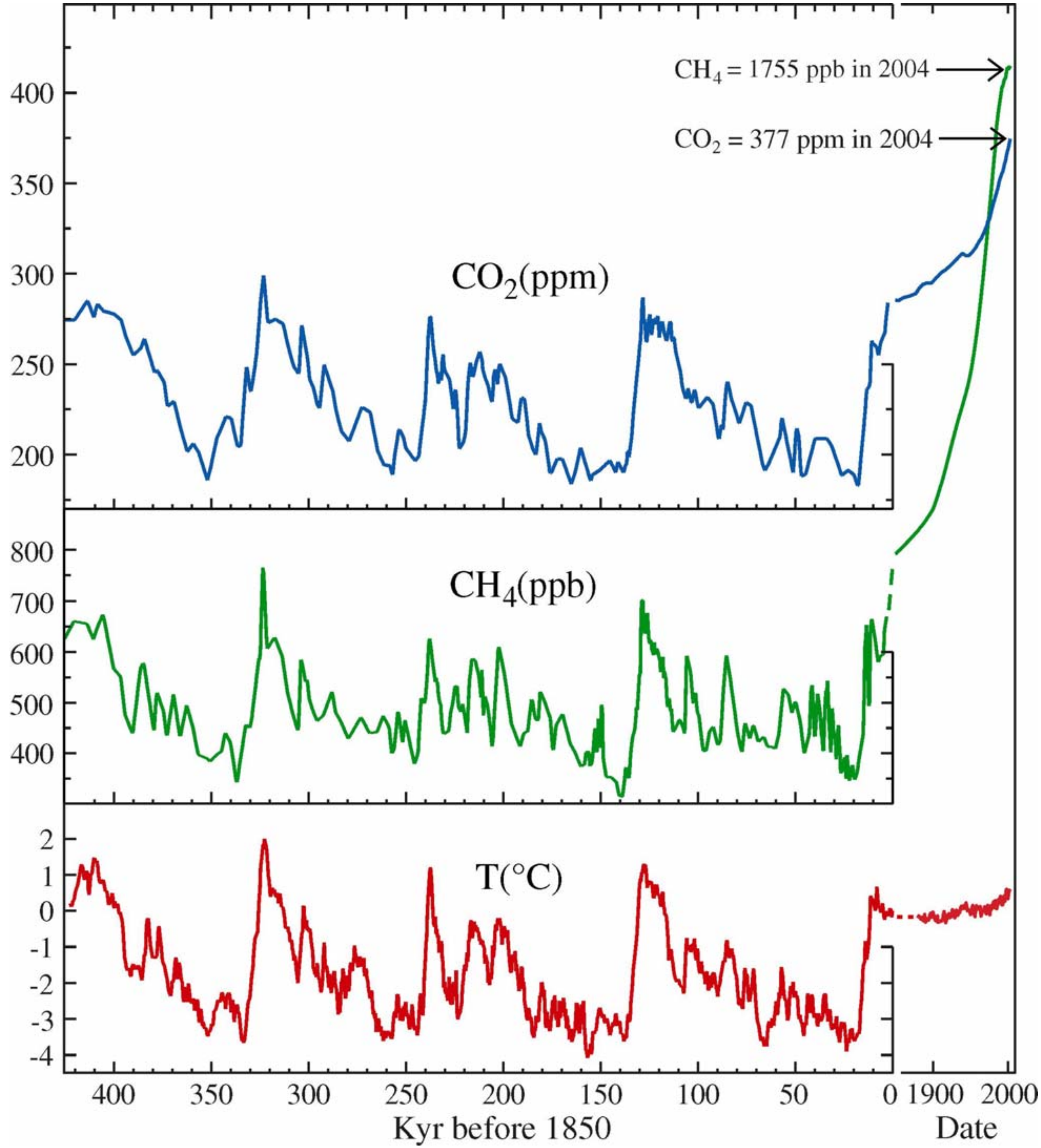
GHGs = CO_2 + CH_4 + N_2O (0.15 forcing of CO_2 + CH_4)



Observations = Vostok ΔT/2.

Calculated temperature = Forcing x 0.75°C /W/m^2

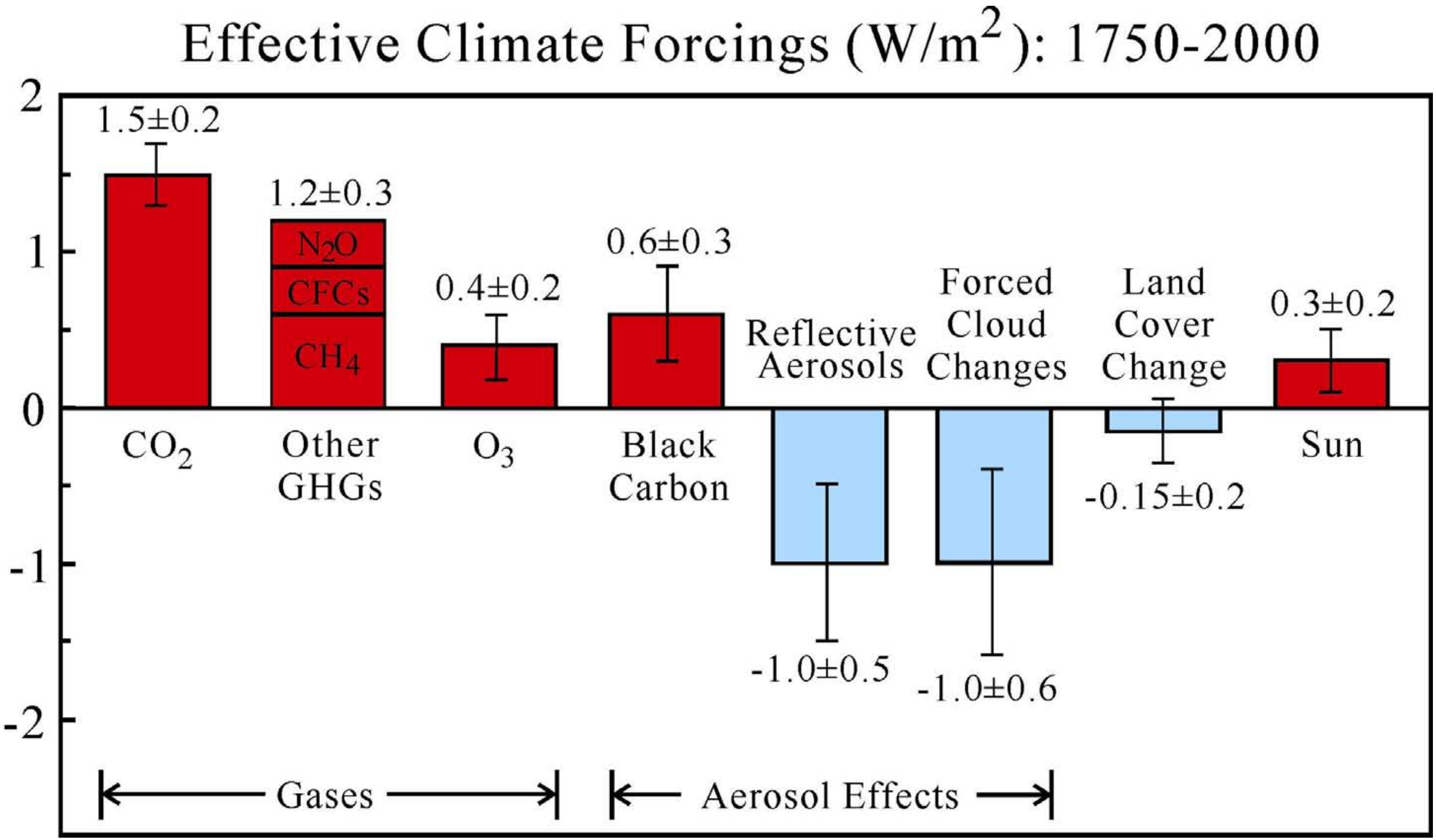
CO_2,CH_4 and estimated global temperature (Antarctic ΔT/2 in ice core era) 0 = 1880-1899 mean.



Source: Hansen, *Clim. Change*, **68**, 269, 2005.

Implications of Paleo Forcings and Response

1. "Feedbacks" (or indirect forcings) cause almost all paleo temperature change.
2. Climate on these time scales is very sensitive to even small forcings.
3. Instigators of climate change must include: orbital variations, other small forcings, noise.
4. Another "ice age" cannot occur unless humans become extinct. Even then, it would require thousands of years. Humans now control global climate, for better or worse.

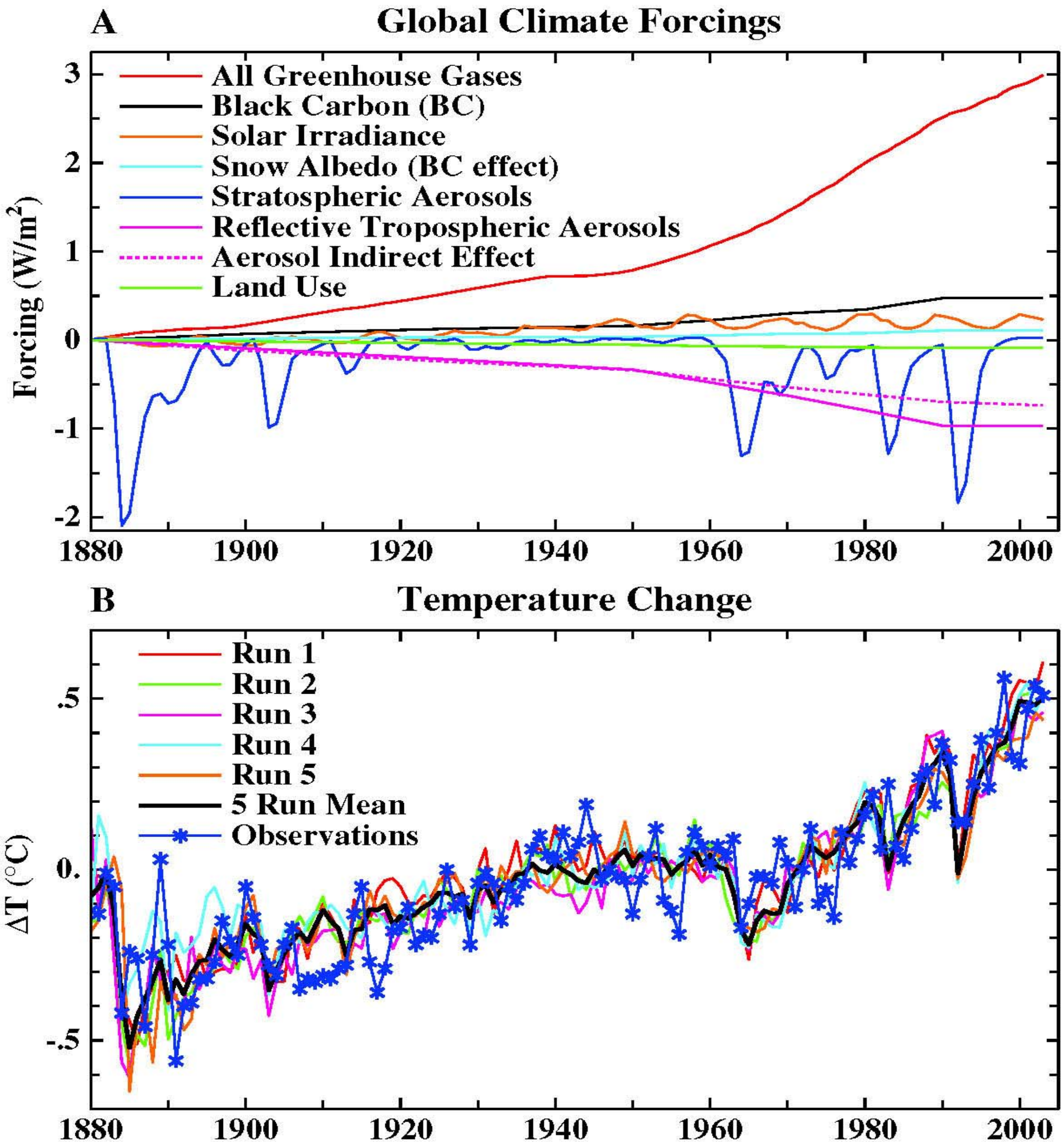


Climate forcing agents in the industrial era. “Effective” forcing accounts for “efficacy” of the forcing mechanism

Source: Hansen et al., JGR, **110**, D18104, 2005.

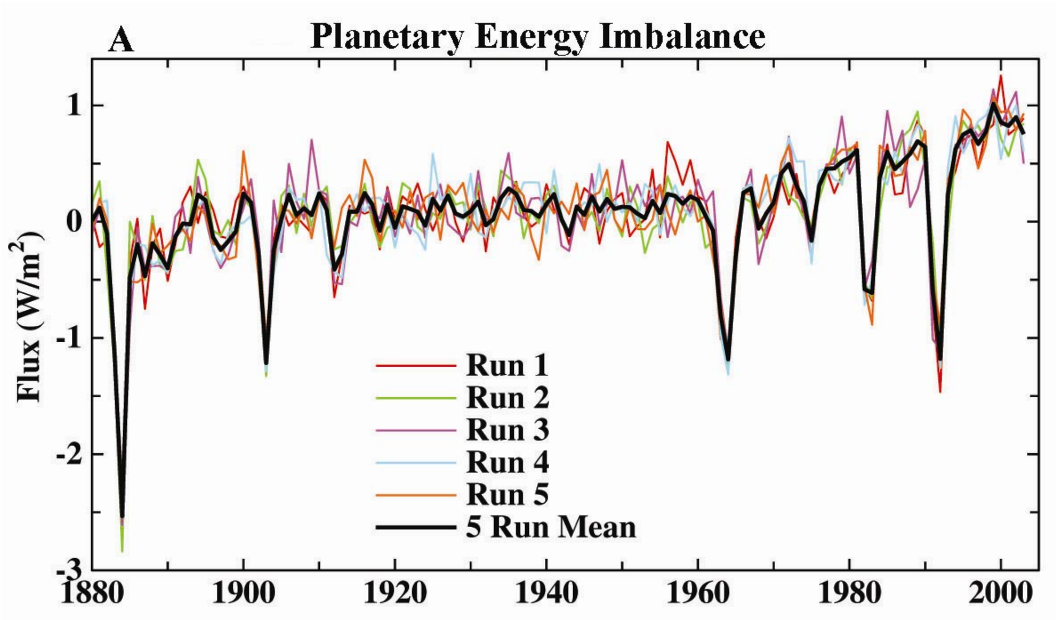
(A) Forcings used to drive climate simulations.

(B) Simulated and observed surface temperature change.

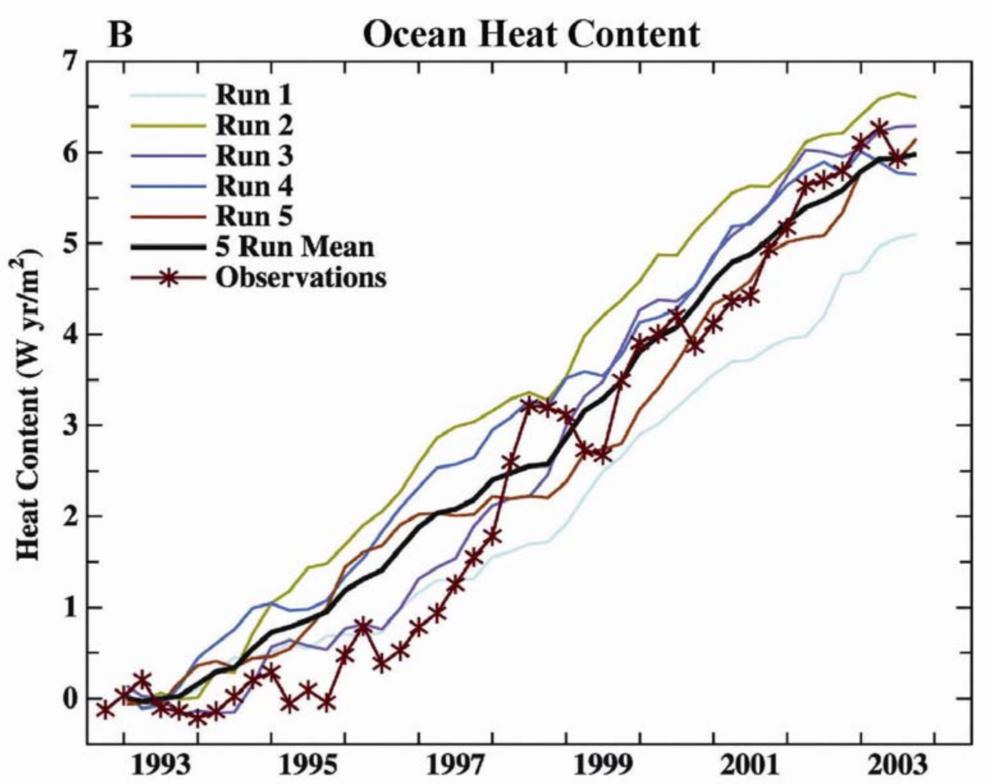


Source: Earth's energy imbalance: Confirmation and implications. *Science* **308**, 1431, 2005.

(A) Net Radiation at top of atmosphere in climate simulations.



(B) Ocean heat gain in the top 750 m of world ocean.



Source: Hansen et al., Science, **308**, 1431, 2005.

Consistency Check

1.85 W/m^2 = 1880-2003 forcing

1.00 W/m^2 = used for observed 0.7°C warming

0.85 W/m^2 = remains, not yet responded to

Implications

1. **0.6°C more warming in the pipeline**
2. **Confirms climate system lag**
   → **Need anticipatory actions to avoid any specified level of "dangerous" change**
3. **Acceleration of sea level rise is likely**

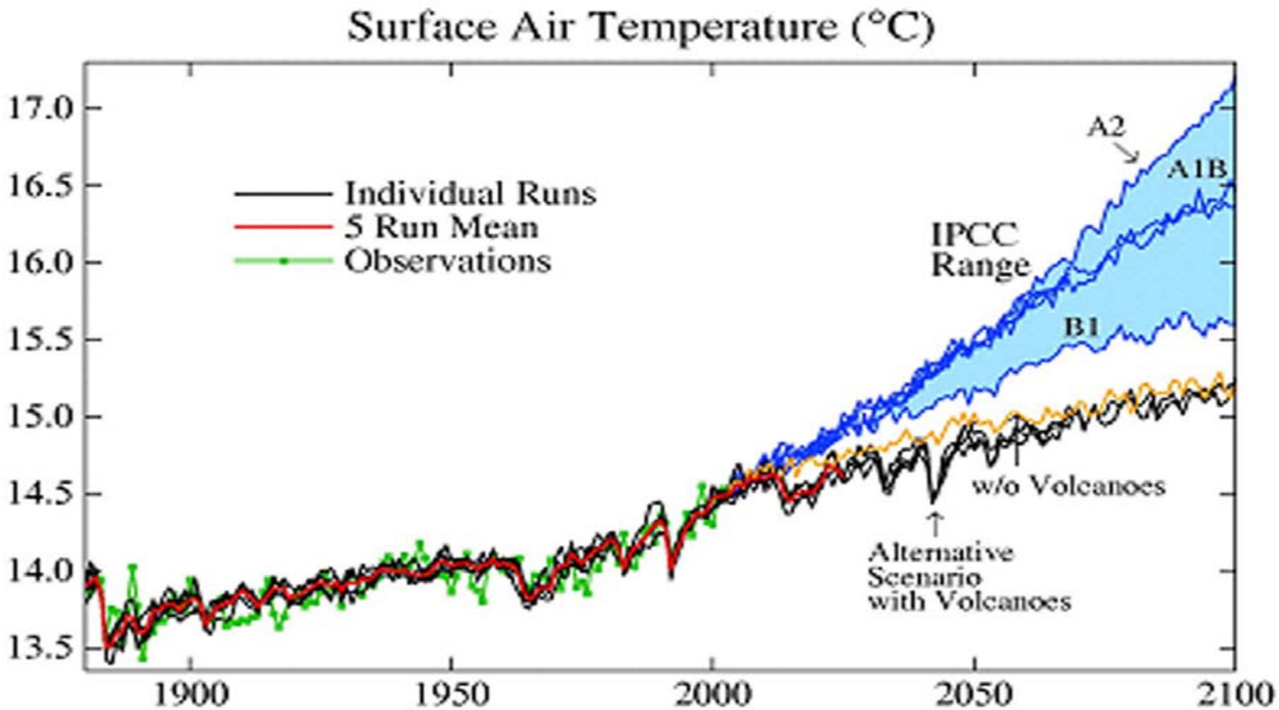
Source: Hansen et al., *Science*, **308**, 1431, 2005.

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."

21st Century Global Warming



Climate Simulations for IPCC 2007 Report

► **Climate Model Sensitivity ~ 2.7°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

Source: Hansen et al., *to be submitted to J. Geophys. Res.*

Metrics for "Dangerous" Change

Physical Climate System Approach

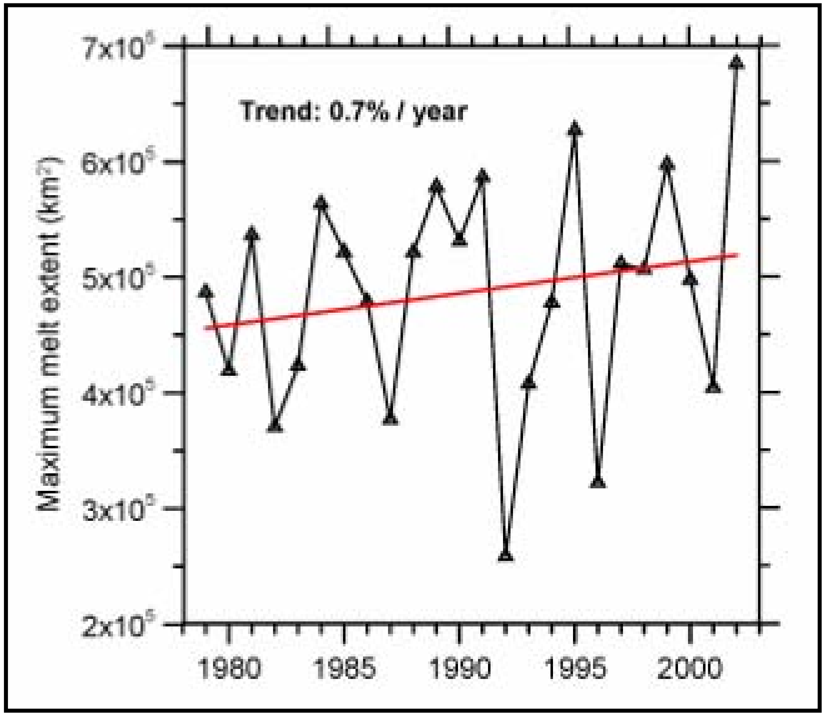
Global Sea Level

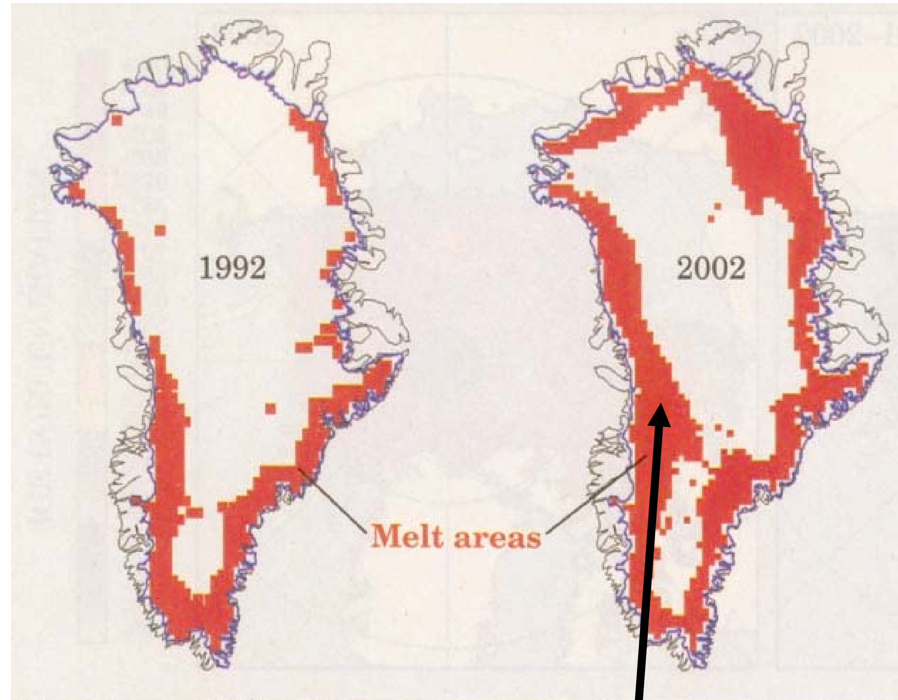
1. Long-Term Change: Paleoclimate Data
2. Ice Sheet Response Time

Regional Climate Change

1. General Statement
2. Specific Cases

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

Jakobshavn Ice Stream in Greenland

Discharge from major Greenland ice streams is accelerating markedly.

Source: Prof. Konrad Steffen, Univ. of Colorado

Regional Climate Change

1. **General Statement**

   Magnitude of Change vs Scenario

2. **Specific Cases**

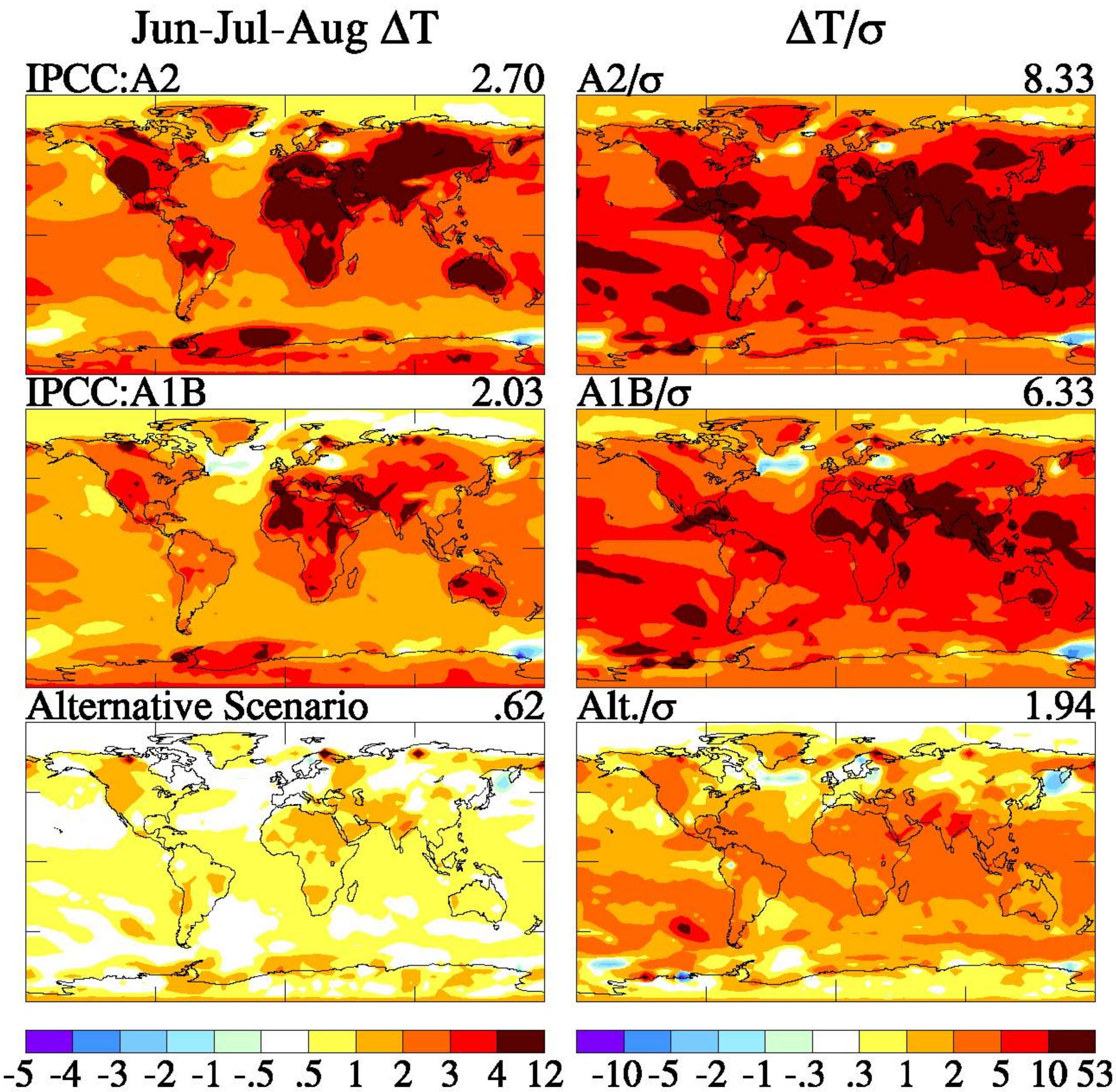
   Arctic

   Tropical Storms

   Ocean Effect on Ice Shelves

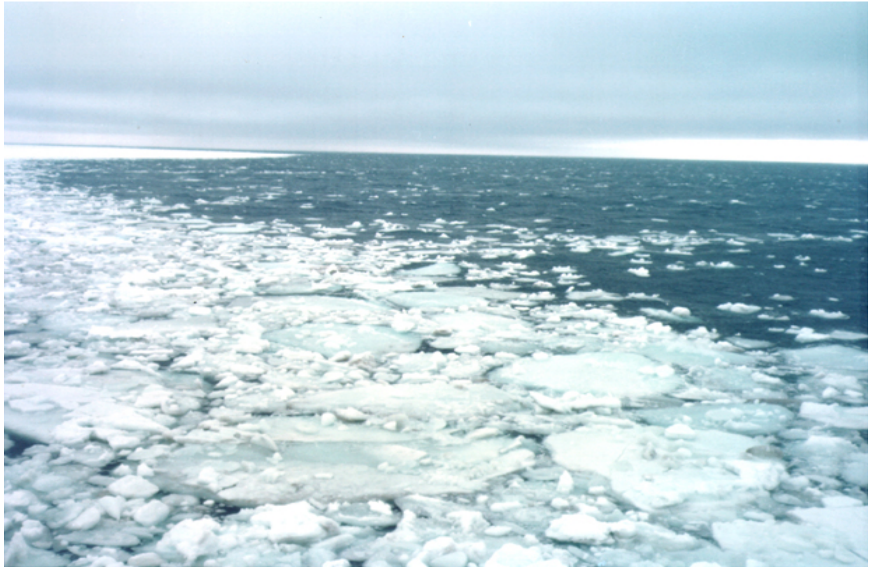
Simulated 2000-2100 Temperature Change

σ is interannual standard deviation of observed seasonal mean temperature for period 1900-2000.



Source: Hansen et al., *J. Geophys. Res.*, submitted.

Arctic Climate Impact Assessment (ACIA)



- 140-page synthesis report released in November 2004.
- Main science report imminent (chapters available electronically at www.acia.uaf.edu).
- Concerns over wide-ranging changes in the Arctic.
  - Rising temperatures
  - Rising river flows
  - Declining snow cover
  - Increasing precipitation
  - Thawing permafrost
  - Diminishing late and river ice
  - Melting glaciers
  - Melting Greenland Ice Sheet
  - Retreating summer sea ice
  - Rising sea level
  - Ocean salinity changes
- Species at risk include polar bears, seals, walruses, Arctic fox, snowy owl, and many species of mosses and lichens

Sources: Claire Parkinson and Robert Taylor

Tropical Storms (Hurricanes)

Our climate simulations provided to IPCC, driven by known climate forcings, predominately increasing greenhouse gases, yield a warming of 0.35°C in the tropical Atlantic region of hurricane formation in 1995-2005 relative to the preceding 25 years. That is the mean result for a 5-run ensemble. The observed warming in that region was 0.45°C. So the categorical contention that recent hurricane intensification is due to a natural cycle of Atlantic Ocean temperature in the region of hurricane formation, and has nothing to do with global warming, is irrational. How could a hurricane distinguish between a natural and greenhouse gas warming? It is not impossible, but it would require an explanation that has not been proffered. I conclude that greenhouse gases are probably responsible for a substantial fraction of the ocean warming that fuels stronger hurricanes.

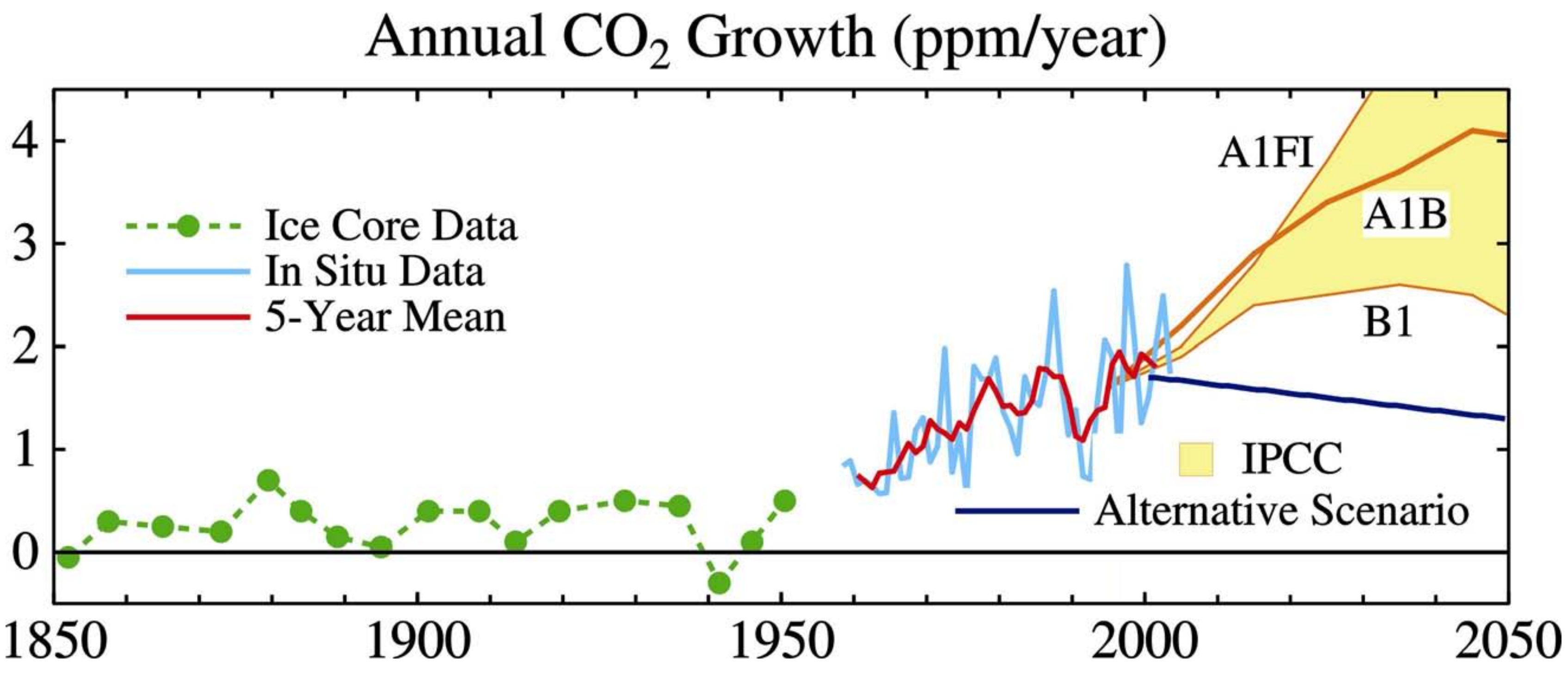
"Tropical Storm Discussion" Omitted From "Keeling" Talk

See www.columbia.edu/~jeh1 re: "Keeling" Talk

“The only way to have real success in science … is to describe the evidence very carefully without regard to the way you feel it should be. If you have a theory, you must try to explain what’s good about it and what’s bad about it equally. In science you learn a sort of standard integrity and honesty.”

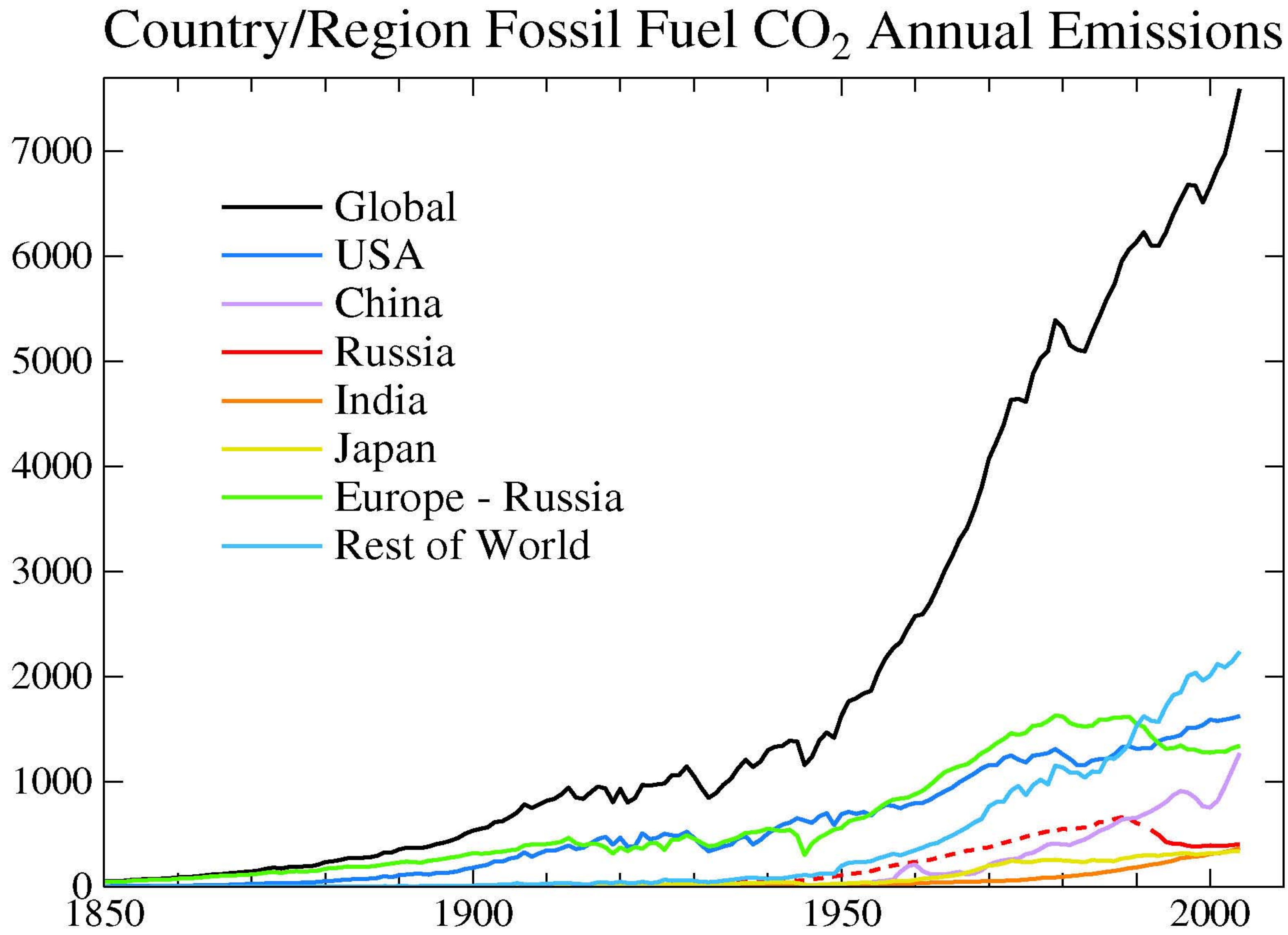
Richard Feynman

See http://www.giss.nasa.gov/edu/gwdebate re “Global Warming Debate”



Growth rate of atmospheric CO_2 (ppm/year).

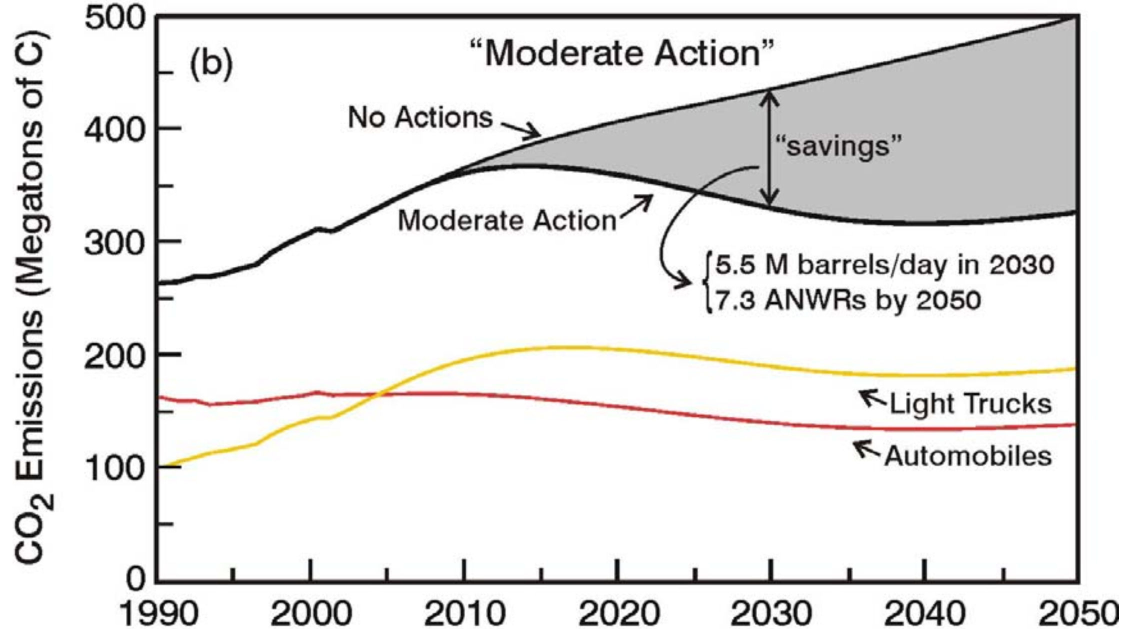
*Source: Hansen and Sato, PNAS, **101**, 16109, 2004.*



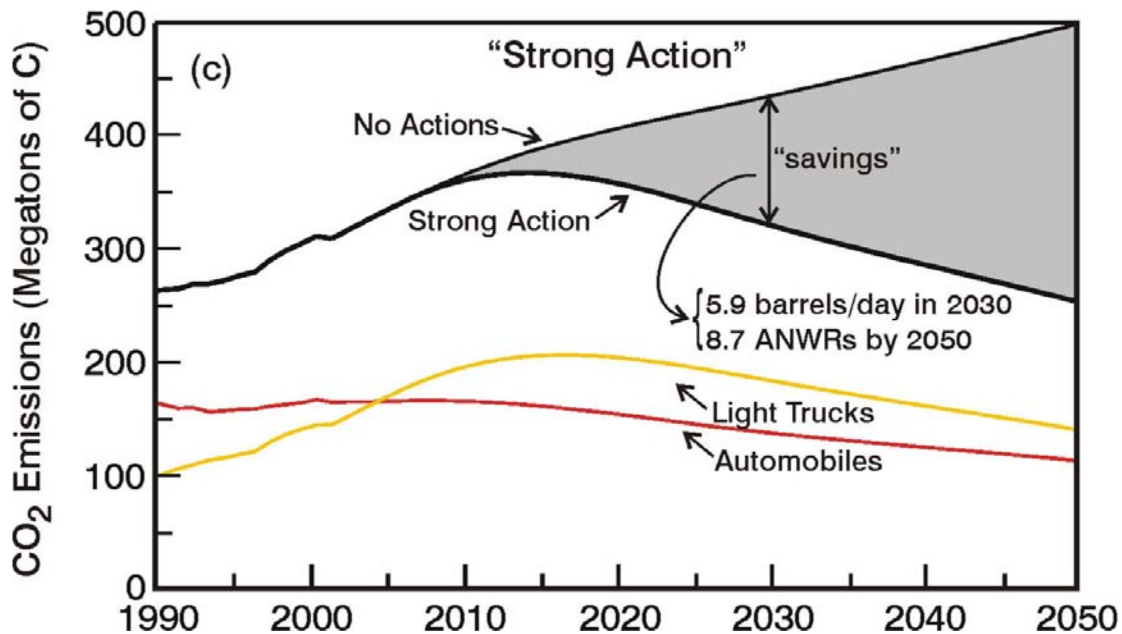
Country/Region Fossil Fuel CO_2 Annual Emissions
Global
USA
China
Russia
India
Japan
Europe - Russia
Rest of World
7000
6000
5000
4000
3000
2000
1000
0
1850
1900
1950
2000

U.S. Auto & Light Truck CO_2 Emissions

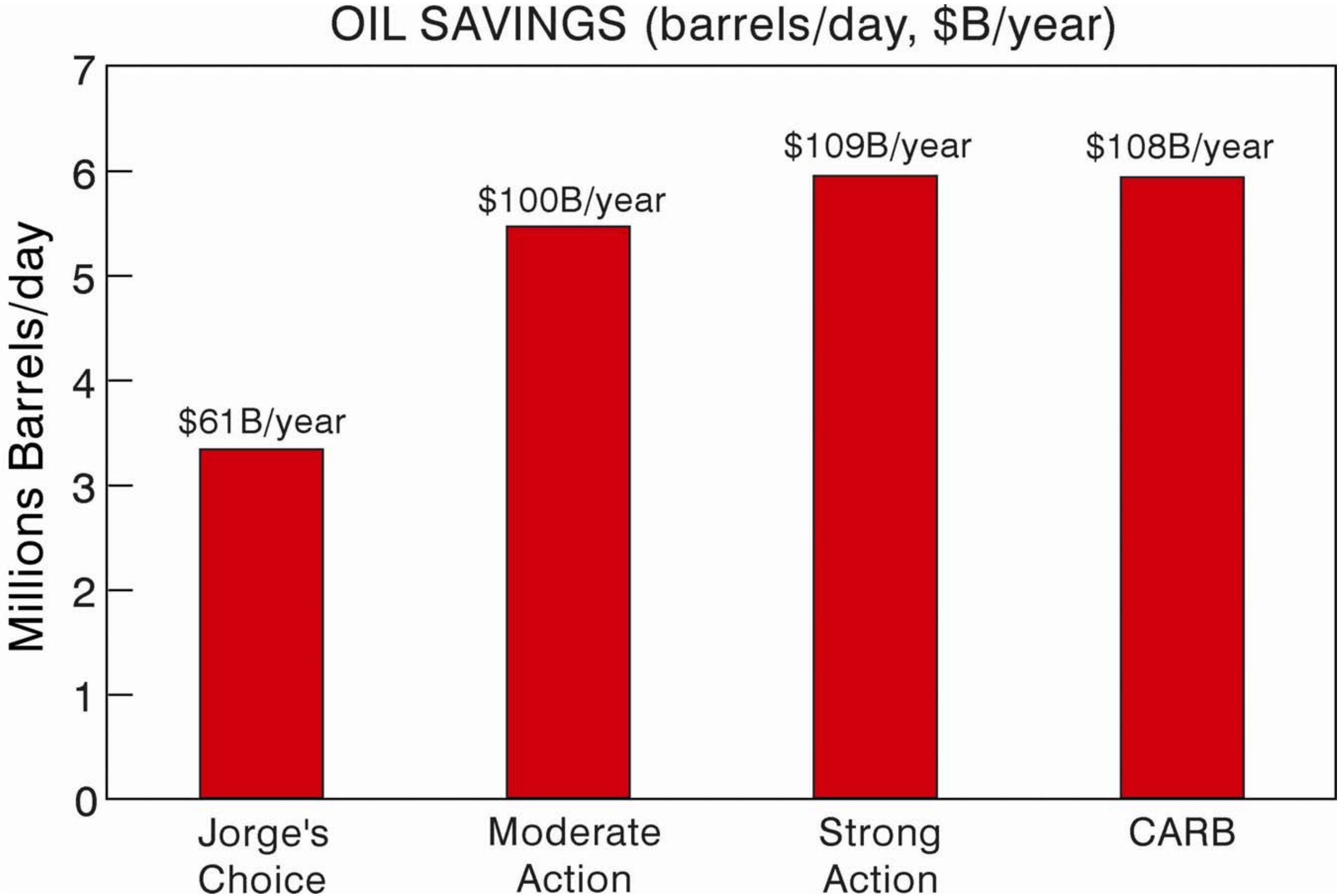
"Moderate Action" is NRC "Path 1.5" by 2015 and "Path 2.5" by 2030.



"Strong Action" adds hydrogen-powered vehicles in 2030 (30% of 2050 fleet). Hydrogen produced from non-CO_2 sources only.

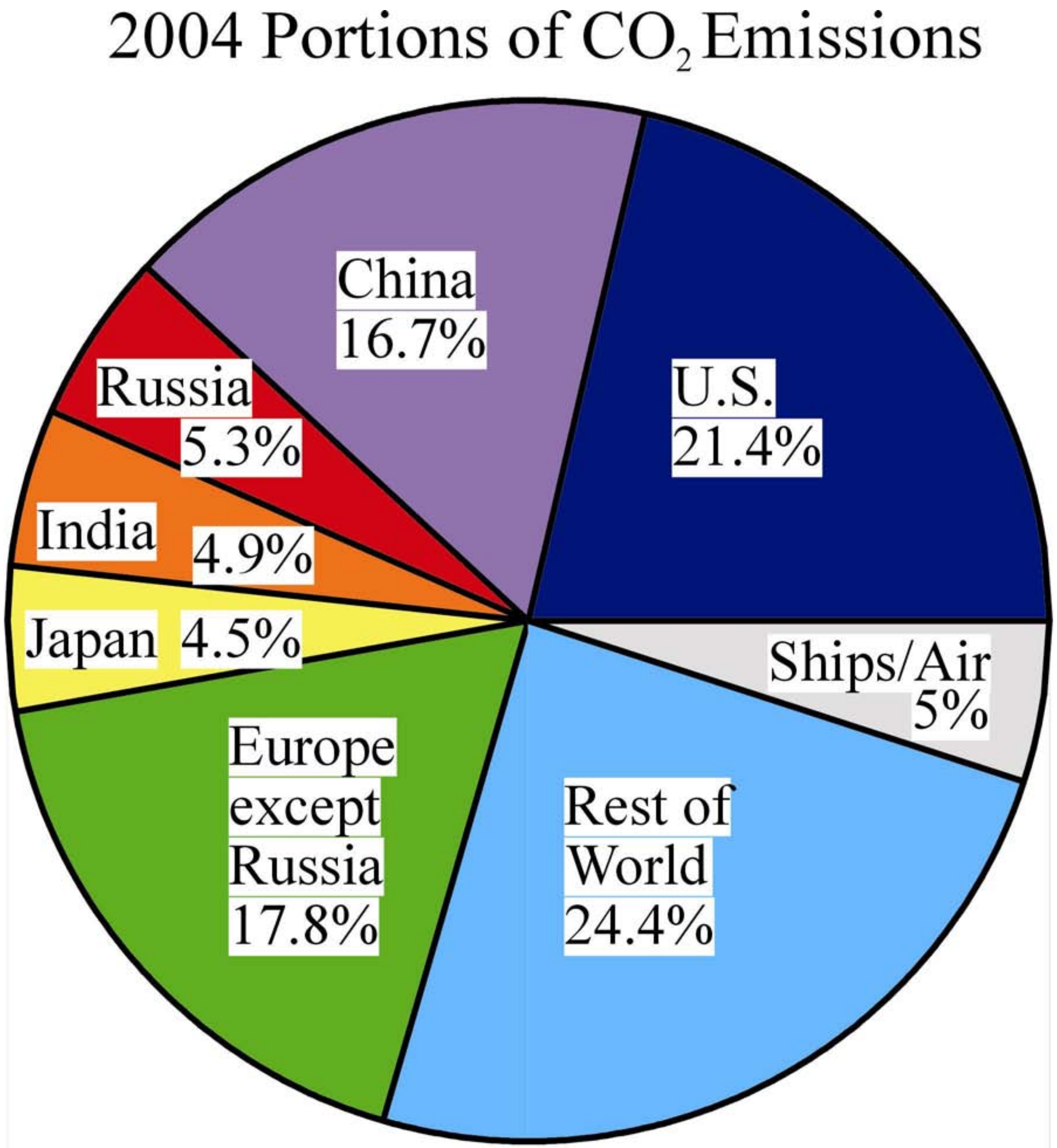


Source: On the Road to Climate Stability, Hansen, J., D. Cain and R. Schmunk., *to be submitted*.



United States annual savings (at $50/barrel, today's dollars) in 2030 for alternative automotive efficiency improvements.

Source: On the Road to Climate Stability, Hansen, J., D. Cain and R. Schmunk., to be submitted.



Fossil Fuel CO_2 emissions by source country in 2004.

Source: Hansen et al, J. Geophys. Res., to be submitted

Workshop at East-West Center, Honolulu

April 4-6, 2005; Local Host: Intn'l. Center for Climate & Society, Univ. Hawaii

"Air Pollution as Climate Forcing: A Second Workshop"

► **Multiple Benefits by Controlling CH_4 and CO**
(benefits climate, human health, agriculture)

► **Multiple Benefits from Near-Term Efficiency Emphasis**
(climate & health benefits, avoid undesirable infrastructure)

► **Targeted Soot Reduction to Minimize Warming from Planned Reductions of Reflective Aerosols**
(improved diesel controls, biofuels, small scale coal use)

► **Targeted Improvements in Household Solid Fuel Use**
(reduces CH_4, CO, BC; benefits climate, human health, agriculture)

Conclusion: Technical Cooperation Offers Large Mutual Benefits to Developed & Developing Nations.

References:
►**Air Pollution as Climate Forcing: 2002 Workshop; 2005 Workshop** http://www.giss.nasa.gov/meetings/pollution02/ and 2005/

Summary: Is There Still Time?

Yes, But:

- **Alternative Scenario is Feasible, But It Is Not Being Pursued**
- **Action needed now; a decade of BAU eliminates Alter. Scen.**
- **We Are All in This Together**
- **Role of the Public & Scientists**