The ever-changing climate system – adapting to the challenges

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There are two fundamental concerns arising from the highly visible issue of climate change. First, how (and why) is the ever-changing climate changing now? And second, what are the consequences, climatic and social, of specific actions designed to affect this ever-changing climate?

## The Climate System

The Earth's climate is not a stable set of statistics that represent the atmospheric system for all time periods. Whether considering temperature, glacier distribution, or sea level height, all indices of climate experience constant change. There have never been two days, two weeks or even two centuries in which the climate was identical in every way. Like the ever-changing eddies in a stream, the climate is typical of nonlinear dynamical systems in which a variety of forces act upon the system leading to responses such as changes in motion, temperature and state which create never-before seen realizations.

On the time scale of climate fluctuations it is important to track the amount of energy in the system to understand responses that may occur. The Earth system stores energy in a wide variety of its components: oceans, lakes, rivers, swamps, ice caps, glaciers, the atmosphere, the upper few meters of the solid earth and the vast array of things which reside on the Earth's surface like plants and animals. Each of these may be thought of as a repository of energy. When any two are out of balance, and they generally are always out of balance, energy flows from one to the other. Just as important, each of these repositories has within it gradients of energy that cause responses which act to smooth out those variations. Thus energy differences force activity within and between the repositories. In the northern hemisphere, for example, we know that warm air typically flows northward and cold air southward as the atmosphere works to smooth out the differences between hot tropics and the cold poles. These basic motions seek to balance the surplus energy in the tropics, generated by intense solar radiation, against the energy deficit at the poles where little solar energy is absorbed.

Assessing the amount of energy in each repository at each point in time will determine whether energy is being exchanged between the repositories, or being retained or lost within a particular repository. In addition, the climate system in its entirety is not in perfect equilibrium from the viewpoint of space. The amount of energy being absorbed from the sun is not exactly equal to the amount emitted to space, but it is fairly close at any given time.

The ocean is the largest repository of climate-scale energy and its height may be thought of as a crude energy-meter since the height of the sea is correlated with the amount of energy (or temperature) in the ocean specifically and the total climate system generally. When the sea level is low, this indicates significant glaciers have formed on land as a result of more snow falling than is melted to replenish what was lost from ocean evaporation, the original source of the snow. Thus a low sea level essentially means a lower global temperature or less total energy in the system.

The Pleistocene period, beginning about 1.8 million years ago and ending 12,000 years ago, was characterized by several large temperature (energy) swings. The last 12,000 years, called the Holocene, has been a warm period similar to other relatively brief warm periods in the otherwise cold Pleistocene. In the Pleistocene, significant portions of the higher latitude land areas and most mountainous regions were covered by ice for tens of thousands of years at a time, with much shorter intervals, or interglacials like our Holocene, characterized by less ice cover.

With such large fluctuations in the land-locked ice, sea level rose and fell as a response. 25,000 years ago near the end of the Pleistocene the sea level was 300 ft lower than today as large ice caps covered areas as far south as Illinois. The climate was so much colder then that the main forest cover in Alabama was the Blue Spruce which now is prevalent in Michigan.

However, 130,000 years ago, during the last interglacial (warm) period, sea level was about 18 feet higher than today, indicating this period was warm enough to melt even more ice than has melted to this point in our own Holocene warm period.[1] These facts indicate sea level, as with temperature in general, is a constantly fluctuating variable, either rising or falling as ice caps grow and decay due to changes in energy availability. So this crude energy meter (sea level height) indicates a period of greater energy retention 130,000 years ago (high sea level, lasting 10,000 years), followed by about 110,000 years of energy loss (lowering sea level) and the recent Holocene period of energy gain (rising sea level). Earth's climate is an ever-changing system.

Factors which affect energy retention

The amount of energy that is absorbed and retained in the climate system depends on many factors; brightness of the sun, the reflection of clouds, the areal coverage of snow and ice, the amount of dust in the atmosphere, etc. It is thought that tiny orbital variations of the Earth led to changes in the amount of sunlight impinging on the Earth which then caused the temperature (energy) variations that created the warming and cooling cycles of the last 1.8 million

[1] Winter, A., O. Tadamichi, H. Ishioroshi, T. Watanabe and J. R. Christy, 2000: A two-to-three degree cooling of Caribbean sea surface temperatures during the Little Ice Age. *Geophys. Res. Lett.*, **27**, 3365-3368.

years, including the warm, cold, warm cycle of the last 130,000 years. In this scheme, certain orientations of the Earth relative to the sun allowed for either an accumulation of energy in the system, leading to warming, or a net loss of energy, leading to cooling.

One factor that effects the energy-retention capability of the Earth is popularly known as the greenhouse effect. The Earth's atmosphere contains certain gases, chief of which is water vapor, which act to retain energy like a sponge. The temperature of the air near the Earth's surface is about 60°F warmer than it would otherwise be but for these greenhouse gases. When water vapor, and other minor gases which include carbon dioxide, methane and low level ozone, experience increases in concentration, the effectiveness of the atmospheric "energy-sponge" is enhanced. Thus as greenhouse gas concentrations rise, all things being equal, the temperature of the air near the surface will rise because more energy is being absorbed.

Many other factors also affect temperature variations. For example, changes in the ocean circulation may reduce the amount of energy transported to regions where more had been transported previously. This factor is likely the cause of some well known cooling events of the past 12,000 years when temperatures were otherwise relatively warm.

Carbon Dioxide

The greenhouse gas of popular concern today is carbon dioxide or CO2. One process that increases CO2 in the atmosphere is the burning of carbon-based fuels such as coal, oil and natural gas. Or, to put it a different way, CO2 is a byproduct of human progress and development, an idea which will be addressed later. The current atmospheric concentration is about 380 parts per million, the highest concentration in at least a million years. In the more distant past, concentrations were much higher, perhaps 5 or more times the current level, and this aided the evolutionary process which allowed for the development and expansion of all of life on the Earth. The biosphere, including human life, would not be here today but for the influence of atmospheric $CO_2$ in concentrations much higher than are now observed. Too, the great coal seams in central Alabama and the limestone formations of North Alabama represent $CO_2$ that was once airborne but now fixed to the solid Earth.

$CO_2$ is not a pollutant. Without atmospheric $CO_2$, there would be no plants or animals. $CO_2$ is best thought of as plant food. There is no doubt that the concentration of $CO_2$ in the atmosphere has risen by a third in the past 300 years and is rising at almost 0.5 % per year as energy production for human development continues to grow.

One consequence of this additional $CO_2$ or plant food, is the increased efficiency of food and fiber production, accounting for about one sixth of the green revolution's increased food productivity.[2] This is a remarkable benefit resulting from this byproduct of human energy production. In another inadvertent but positive consequence, it may well be that humans have forestalled the onset of the next ice age, a climatic event that would be devastating to current human existence.

However, $CO_2$ is a greenhouse gas and thus as concentrations increase, is acting to make the atmospheric "energy-sponge" more effective, causing more energy to be retained in the climate system. All things being equal, air temperatures should rise.

In the past 100 years the air temperature near the surface has risen about 1°F according to a scattered set of changing thermometers placed in mostly inhabited

[2] Wittwer, S., 1995: Food Climate and Carbon Dioxide. CRC Press Boca Raton, FL, 236 pp.

regions of the world, and where ships have sailed. About half of the rise occurred prior to 1945 indicating human-based when energy production of $CO_2$ would have had very little impact. The remaining warming has occurred since about 1979 after a 35-year slight-decline in global temperatures.

There have been other centuries where similar temperature changes have occurred, but such changes are not common as indicated by the crude records of temperature from indicators like tree rings and ice cores. It is thus highly likely that some of the increase in air and ocean temperature of the past century is due to retention of energy brought about by increases in greenhouse gases from burning carbon-based fuels.

The atmosphere, and the climate system in general, is an intertwined system of interrelated mechanisms that respond to changes in energy. When something perturbs the energy-holding capacity, some processes act to increase the energy-holding capacity even more, so-called positive feedbacks. For example, if increased $CO_2$ causes the air to warm and then leads to increased evaporation from the oceans, this additional water vapor, being a powerful greenhouse gas, will cause even more energy to be retained and the temperature to rise more than would be due to $CO_2$ alone. Suppose, on the other hand, this additional water vapor produced more cloudiness in the lower atmosphere, which then led to more sunlight being reflected back to space, a cooler temperature would result. This is an example of a negative feedback.

Other aspects of human development also lead to warmer temperature readings at the thermometer sites in different ways. Land-use changes, such as urbanization or deforestation, generate higher temperatures. The soot and pollution which hangs over third world cities and countrysides from burning biomass (wood, dung) also enhances the atmospheric energy-sponge effectiveness and produces warmer temperatures. It has even been hypothesized that irrigation in arid climates causes daily average temperatures to be higher due to a warming of the nighttime temperatures.[3] Thus, part of the rise in near-surface temperatures of the past century is human-related, but not due to the greenhouse effect.

In summary, there are complex natural forces which influence the amount of energy in each of the components of the Earth's climate system. Continuous and changing interactions among the components produce a climate system that is always changing. The natural greenhouse effect is responsible for 60°F of warmth, providing a climate that supports life on the Earth's surface. There are now (a) the extra influence of rising atmospheric concentrations of minor greenhouse gases and (b) the impacts of land-use changes related to human development which affect temperature. The magnitude of this greenhouse effect will increase as more CO2, or plant food, is placed into the atmosphere and this will likely cause an increase in temperature. Also, sea level will continue its 20,000-year rise, perhaps as much as one inch per decade, until the next ice age begins. (This will happen regardless of the enhancement of the atmospheric "energy sponge" due to burning fossil fuels.) Finally, the evidence indicates the Earth has experienced periods relative to that observed today that were warmer, with higher sea levels and with considerably more CO2 in the atmosphere.

Policy

Providing useful information about the future state of the climate to guide planning, mitigation and adaptation is a difficult undertaking. The nuances of the way energy is absorbed, transferred and ultimately escapes from the Earth are too complicated to be fully and accurately expressed in computer forecast models. For example, the manner in which positive and negative feedbacks will evolve in the climate system is not known with confidence. Much effort has been

[3] Christy, J.R., W.B. Norris, K. Redmond, and K. Gallo, 2006: Methodology and Results of Calculating Central California Surface Temperature Trends: Evidence of Human-Induced Climate Change? J. Climate, 19, 548-563.

poured into refining climate models, but by in large, significant aspects of their representation of the climate system are still not in line with observations.

Virtually all models over-predict temperature increases that have occurred in the past 25 years, yet these same model outputs are the basis for creating concern, indeed alarm, about the trajectory of the future climate. Along with this process of trying to understand the climate is a media industry which relies on that which is alarming to sell its product. Thus the most dire-sounding climate scenarios, usually those that have no chance of occurring, are given widespread media coverage. The following example from *Newsweek* is sobering in this context.

> There are ominous signs that the earth's weather patterns have begun to change dramatically and that these changes may portend a drastic decline in food production – with serious political implications for just about every nation on earth. The drop in food output could begin quite soon, perhaps only ten years from now. The regions destined to feel its impact are the great wheat-producing lands of Canada and [Russia] in the north, along with a number of marginally self-sufficient tropical areas – parts of India, Pakistan, Bangladesh, Indochina and Indonesia – where the growing season is dependent upon the rains brought by the monsoon.
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> The evidence in support of these predictions has now begun to accumulate so massively that meteorologists are hard-pressed to keep up with it. … The central fact is that after three quarters of a century of extraordinarily mild conditions, the earth's climate seems to be cooling down.[4]

[4] *Newsweek*, 28 April 1975, pg. 64.

This illustrates that the treatment of scientific issues in the popular real-time media, where most people receive news information, is generally poor regarding complicated and ambiguous issues. However, in democratic nations, it is popular perception that often drives policy. Thus the perception of a looming disaster, if aggressively marketed, will likely initiate calls to mitigate the "problem".

To paraphrase Lord Kelvin, "All science is numbers." It behooves the public and policymakers to focus on the objective magnitudes of change to understand whether significant change is occurring, what kind of change that is, the potential threat such change might inflict and whether diverting resources to mitigate the change is useful in a cost-benefit analysis.

There have not been, for example, increases in the frequency of hurricanes, droughts, floods, storms, blizzards, tornadoes and other weather events which can significantly affect human infrastructure.[5] Yet, when they occur in the modern information-gathering age, it is common for such events to be reported as consequences of human induced climate change.

Melting glaciers are often cited as evidence of human-induced climate change. However, mountain glaciers that are melting now, were in many cases non-existent in the recent few thousand years. The delicate glaciers of Kilimanjaro are disappearing, but this is more likely due to a general drying of the tropical atmosphere in this region that began over a century ago, and not to enhanced greenhouse gasses. They have disappeared before. Glaciers, like climate and

[5] Folland, C.K., T.R. Karl, J.R. Christy, R.A. Clarke, G.V. Gruza, J. Jouzel, M.E. Mann, J. Oerlemans, M.J. Salinger and S.-W. Wang, 2001: Observed climate variability and change. In: Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change [Houghton, J.T., Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X Dai, K. Maskell, and C.A. Johnson (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 881 pp.

sea level, are always growing or melting. There simply is no fixed, standardized level of stability to be achieved in the climate system (an important scientific fact to consider when dealing with calls for action.)

The temptation for many is to point to any change and ascribe its cause to "global warming". For example, any heat wave in the Midwest is tied to human-caused "global warming." Yet a scientific analysis (i.e. numbers) shows that of the 10 worst heat waves in northern Illinois in the past 120 years, only 3 occurred since 1950 and they ranked 3rd, 4th and 9th.[6] Also, rumors persist of declining polar bear populations due to "global warming", though the meager evidence available suggests there has been a 15% increase in the past 25 years.[7] (Inuit villagers are requesting an increase in their hunting quotas to reduce the threat.) The temperatures in Alabama have declined significantly since 1895.[8] And in research performed by the author, the bulk global atmospheric temperature, indicating the amount of energy being retained, is increasing at a rate less than any climate model projections portend.[9]

Arctic sea ice extent has decreased since 1975, a phenomenon clearly related to warming in that region, but is so widely reported it is a ubiquitous feature of alarmist presentations. Over the same period however, sea ice extent has actually increased in Antarctica, but this scientific observation routinely goes

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[6] Kunkel, K.E., S. A. Changnon, B. C. Reinke, and R. W. Arritt, 1996: The July 1995 heat wave in the Midwest: A climatic perspective and critical weather factors. *Bull. Amer. Meteor. Soc*., **77**, 1507-1518

[7] McCauley, C. "Polar bears defy extinction threat", The Scotsman, 7 Feb 2005, http://thescotsman.scotsman.com/international.cfm?id=143012005 and "Nunavut rethinks polar bear quotas as numbers drop", http://www.cbc.ca/story/canada/national/2005/06/09/polar050609.html

[8] Christy, J.R., 2002: When was the hottest summer? A State Climatologist struggles for an answer. Bull. Amer. Met. Soc. 83, 723-734.

[9] Christy, J.R. and W. B. Norris, 2004: What may we conclude about global tropospheric temperature trends? *Geophys. Res. Lett*. 31, No. 6. and Christy, J.R. and R.W.Spencer, 2005: Correcting temperature data sets. Science, 310, 972.

unreported.[10] Additionally, recent measurements indicate that oveall Greenland and Antarctica ice caps are not decreasing.[11,12]

Given that climate is ever-changing, it is important that science be brought to bear to avoid the enactment of regulations based on popular, but uncertain alarms, and mitigation strategies that are ineffectual.

It was known relatively early, for example, that the Kyoto Protocol, which sought a 5% reduction in greenhouse gas emissions from the 40 highly developed countries, was not going to affect the global temperature by an amount that was even measurable.[13] Thus, scientifically, the Kyoto Protocol, even if adhered to, would be ineffectual. And, it is now apparent that even many of those who signed the treaty will exceed their quotas of greenhouse gas emissions.

Various scientific organizations have issued their own accounts of what the climate is doing and whether specific human actions would have any measurable impact. Some of these organizations have subtle, anti-development or pro-development agendas, and thus their reports will be slanted accordingly.

The most prominent of the scientific climate assessments is produced by the United Nation's Intergovernmental Panel on Climate Change, written by scientists selected for their expertise or position in government, every few years, the first being in 1990. These IPCC assessments on the climate basically have stated that there is evidence that many of the recent changes in climate are natural but others, principally the rise in global average temperature, appear to

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[10] Folland, et al. 2001
[11] Johansnessen, O.M., K. Khvorostovsky, M.W. Miles and L.P. Bobylev, 2005: Recent ice-sheet growth in the interior of Greenland. Science, DOI:10.1126/Science.1115356.
[12] Davis, C.H., L. Yonghong, J.R. McConnell, M.M. Frey, E. Hanna, 2005: Snowfall-driven growth in East Antarctic ice sheet mitigates recent sea-level rise. Science, 308, 1898-1901.
[13] Wigley, T.M.L., R. Richards and J.A. Edmonds, 1996: Nature, 240, 379.

be related to human impacts on the climate system. More difficult to assess with confidence though are whether important aspects of regional climate are changing as a result of human influence, i.e. droughts, floods, etc.

Other parts of the IPCC assessment attempt to address specific impacts, adaptations, vulnerabilities and mitigation strategies to climate changes. Results from these impact studies garner even less confidence because developing predictive models for biological systems and human responses are not well-advanced. And, importantly, they require specific, *future* climate information which, as noted earlier, is not well-known from models. Finally, even more difficult to predict is how human systems will innovate and respond as time unfolds.

The history of human development is characterized by unpredictable advances in technology which render moot problems once deemed catastrophic. For example, a century ago it was feared that sustaining the most common mode of transportation, the horse, in a growing economy would lead to an economic collapse, particularly in the major cities. The problems of waste removal, attendant diseases and massive amounts of land needed for feed production were becoming overwhelming. But, at that same time, the automobile and electrified mass transit entered the market and changed everything.

The evidence shows that human development is a continuing process slowed only by catastrophe or war. Energy for transportation, indoor environmental control and electricity production is a foundation for economic development. Most of this energy is produced today by burning carbon in some fashion. Thus for at least the first decades of the $21^{st}$ century, we should expect to see atmospheric CO2 levels increase. It is likely, therefore, that temperatures will rise as well. The current rate is a modest 0.3 °F per decade near the surface.

The United States produces about 23% of the global human emissions of $CO_2$ and about 29% of the world's goods and services.[14] Thus, on an efficiency bases, the U.S. is better than the rest of the world combined. Consider also that though the U.S. energy production is rising, the energy intensity, a measure of $CO_2$ emissions versus constant-dollar GDP, has declined by 50% since 1970.[15] This is due to the functioning of a market economy which constantly seeks the lowest cost to produce something, and energy is one of those costs.

Overall, the picture is one of modestly rising global average temperatures, but with unpredictable regional changes. It is not clear how much of the recent rise in global average temperatures is due to enhanced greenhouse gases much less whether regional changes may be human-induced.

It would be even more difficult to determine any direct climate impact of policies designed to affect the climate. The climate is always fluctuating, so this confounds any attempt to determine what part of the fluctuation might be due to a particular policy and that part due to natural variations, especially when the policy action is minuscule relative to the entire climate system. Without such certainty in outcomes, one is unable to offer "solutions" which address "problems" with definitively identified "success".

The freedom and opportunity to use energy for transportation, environmental control and devices to aid our daily lives, has brought significant increases in life-spans and quality of life in general. It is important to realize that human populations rarely choose to reduce their standard of living (i.e. health, security, comfort, mobility, etc.) for goals that are unmeasurable, uncertain and costly. As Prime Minister Tony Blair stated:

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[14] Energy Information Administration, Flash estimate, 2004, http://www.eia.doe.gov/; World Development Indicators, World Bank, http://web.worldbank.org/

[15] Energy Information Administration, http://www.eia.doe.gov/

> I think if we are going to get action on this, we have got to start from the brutal honesty about the politics of how we deal with it. The truth is no country is going to cut its growth or consumption substantially in the light of a long-term environmental problem.[16]

Add to this notion the fact that many of the politically-acceptable regulatory actions proposed to mitigate human-induced climate change will have virtually no measurable impact on the climate system or have impacts that are largely unpredictable. The regulatory path seems ineffective for reducing CO2, unlike the pathways available for dealing with toxic pollutants such as sulfur oxides, nitrous oxides and chemicals that destroy stratospheric ozone.

Access to affordable energy is highly correlated with standard of living, including the quality and length of human life. Affordable energy, therefore, will likely remain a fundamental goal of democratic (and other) governments worldwide. And preventing less-developed countries the opportunity to create sources of affordable energy for their populations should not be a path to advocate if one values human life.

The author, while living in Kenya, witnessed the energy system there. Women and children would rise early, walk miles to the forest edge, chop and bundle large branches of wood, hoist these on their backs and walk back to their homes. In the mainly mud-walled and thatched-roofed homes, the wood was burned for warmth, cooking and light. The emissions (smoke) were highly toxic leading to respiratory and eye diseases which lowered the Kenyans' quality of life and shortened life spans considerably. The U.N. estimates world-wide about 1.6 million women and children die prematurely from indoor smoke each year. This energy system prevents women and children from participating in pursuits of progress, which in my experience they would rather do. Given a choice of participating in the above energy gathering system or using a microwave oven

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[16] Blair, A., Clinton Global Initiative, 15 September 2005.

with electricity produced from a coal-fired power plant, the choice becomes obvious, liberating and life-enhancing. (In these situations where energy access is still primitive, the greatest threats to standard of living and quality of life are related more to dysfunctional governance and/or repressive regimes, not potential climate change.)

To have a measurable impact on global temperature, as in reducing the rise from 0.3 to 0.1 °F per decade, a radical reduction in carbon emissions would be required while maintaining the base loads needed by society. There have been many studies which have addressed this issue, most concluding that proposals advocating such non-carbon based solutions as wind and solar power combined with conservation measures will simply not provide measurable results. Major reductions in CO2 emissions would be achieved only with significant energy output from nuclear fission or new, yet undeveloped types of generation (e.g. nuclear fusion).[17] (Ideas for significant CO2 sequestration have yet to be demonstrated, but hold some promise.) These hoped-for low-carbon or no-carbon energy strategies will be developed by the wealthiest countries who have at their disposal significant and affordable sources of energy today.

Because accessible energy enhances life significantly, energy production for human enterprises will continue to increase and much of it will be carbon-based for the next few decades. It is likely that the modest and/or ambiguous changes in global climate that seem to relate to human activity will not be overwhelming enough to serve as an impetus to cause human populations to accept rationing of energy, i.e. a reduction of living standards, as is popularly proposed by environmental activists today. The real surprises of the future will likely not be in the sphere of climate change, but in the ingenuity of scientists and engineers

[17] Hoffart, M.I. et al, 2002: Advanced technology paths to global climate stability: Energy for a greenhouse planet. Science, 298, 981-987.

who develop new or modified systems for energy generation that emit little or no $CO_2$. Given this, I am optimistic about the future.