

Climate in the Balance

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Life requires energy. It is the sun's energy that sustains most forms of life on Earth and that drives our climate system. On the other hand, energy produced from the burning of coal, oil, and natural gas (so-called fossil fuels) lights our cities, heats our homes, fuels our cars, and powers our iPods. Fossil fuel-derived energy has afforded us a wonderful quality of life, especially in the developed world.

Here is the paradox: the energy that lights our dark nights, keeps us warm, and powers our cars also produces lots of greenhouse gases that serve to alter the Earth's energy balance and cause our climate to change.

We find ourselves today at a unique time in Earth's 4.5 billion year history. Humans, through our expanding population and the burning of fossil fuels, are now a geological force capable of altering the Earth's energy balance. The resulting climate change will have significant and profound consequences for the health of the world's ecosystems and human well-being.

This essay poses questions about, and offers answers to how our climate system works, how humans are changing the climate system, and how we might face the challenges of reducing our negative impact on the climate system in the future.

Professor Wake, isn't the climate system too complex for us to really understand?

The climate system is complex, but there are some basic features of the system that allow us to understand how it works. And how we are changing it. Our climate system is the result of a tricky balancing act between incoming short-wave radiation from the sun and outgoing long wave radiation emitted by the Earth.

Greenhouse gases in our atmosphere (the major ones being carbon dioxide, methane, nitrous oxide, and water vapor) serve to trap heat at the surface of the Earth,

much the same way a blanket serves to keep you warm on those cold New Hampshire nights. Greenhouse gases do not interact with the shortwave radiation from the sun, but they do interact with long wave radiation emitted from the Earth. So, the sun's radiation heats up the Earth and the Earth re-emits that energy as long-wave radiation that is trapped by greenhouse gases.

Natural levels of greenhouse gases in the atmosphere (the greenhouse effect) maintain a very pleasant climate; without them our planet would essentially be a large snowball with average temperatures hovering around 0°F. It is difficult to envision higher forms of life evolving on a frozen planet.

Let's place this solar energy into perspective. The amount of solar energy actually absorbed by the Earth's surface is about 10,000 times greater than the amount of energy we produce from all sources including fossil fuel, nuclear, and hydroelectric power.

How can humans possibly change the Earth's climate when the energy we produce is only a small fraction of the energy produced the sun?

It is not the energy we produce that is changing the climate. It is the emissions of greenhouse gases produced by the burning of fossil fuels that are changing climate, i.e., the enhanced greenhouse effect or global warming. Natural levels of greenhouse gases are good things. But too much of anything can be detrimental. For example, we know water is also critical for life. But too much water, as we experienced during the floods last May, is not good. The same is true for greenhouse gases. When we burn fossil fuels, we are essentially oxidizing the carbon that has been stored in the Earth's crust. The products are energy and carbon dioxide, a greenhouse gas. We now burn so much fossil fuel that we have significantly changed the carbon dioxide content of the atmosphere.

How do we know? Carbon dioxide has been measured in the atmosphere at the Mauna Loa Observatory on the big island in Hawaii since 1958 (*Figure 1*). The seesaw pattern, represented by the red line, reflects the inhalation and exhalation of the northern hemisphere terrestrial biosphere—essentially forests, grasslands, and agricultural ecosystems. Photosynthesis during the spring and summer causes carbon dioxide levels in the atmosphere to fall, while respiration (especially all those bacteria decomposing dead plant material) in the autumn and winter cause carbon dioxide levels in the atmosphere to rise.

The long-term increasing trend, represented by the blue line, is the result of the transfer of carbon from the crust to the atmosphere from the burning of fossil fuels. We know from analysis of air bubbles preserved in deep, old ice in Antarctica that the levels of carbon dioxide in the atmosphere today (about 380 parts-per-million) are 30 percent higher than they have been for the past 420,000 years (*Figure 2*).

Hasn't climate always changed?

Excellent observation! Humans are now just one of a variety of factors that can cause climate to change. The recent increase in carbon dioxide and other greenhouse gases has changed the Earth's energy balance and, as a result, changed our climate. Scientists working around the world have collected detailed records of past climate change by deciphering climate records stored in the annual layers of trees, corals, and glaciers. They have also collected historical and instrumental records of climate change. These records have been combined into a single record that documents temperature change for the northern hemisphere over the past 1000 years (*Figure 3*). This figure, often called the "hockey stick" plot because of the shape of the temperature trend, shows that the last few decades have been the warmest of the last millennium.

Air temperatures have also been measured directly at many stations around the globe. These data have been examined and averaged to produce a record of global temperature changes over the past 120 years (*Figure 4*). The Intergovernmental Panel on Climate Change (IPCC) has assembled a group of hundreds of climate scientists to assess the causes of the recent warming trends. Using a variety of tools, including well documented global circulation models, they have concluded that most of the warming observed over the last 30 years owes to human tampering with the climate system by increasing greenhouse gases in the atmosphere.

Interestingly, the temperature record also shows a

slight cooling from about 1940 to 1970. It turns out that when we burn fossil fuels, a gas called sulfur dioxide is also emitted into the atmosphere. Sulfur dioxide is quickly oxidized in the atmosphere to form sulfate particles, which actually serve to reflect incoming short wave radiation (the particles, unlike the greenhouse gases, do interact with solar radiation) and cool the regions downwind of where the sulfur dioxide is emitted.

Sulfate particles are not, however, a solution to the global warming problem. First of all, they love water and so only stay in the atmosphere a few days before they are washed out; they cool the planet on a regional basis and for relatively short periods of time. (By contrast, the atmospheric lifetime for the average carbon dioxide molecule is 100 years!) Second, sulfate particles have their own particular problems. They are responsible for much of the acid rain that is degrading our ecosystems in the Northeast, and are a major problem for human health, resulting in premature mortality of thousands of Americans each year.

What about New England? Analysis of the best available meteorological data indicates that the region has warmed on average about 2°F over the last 100 years. There has been an increase in the rate of warming over the last 30 years, and this warming trend has been especially apparent in winter, where we have observed a temperature increase of 4.4°F in the past three decades. This has been accompanied by earlier breakup of lake ice in the spring, a decrease in snowfall, a decrease in the number of days with snow on the ground, and earlier spring bloom dates for lilacs, apples, and grapes. Clearly, our regional climate is changing and the rate of change has increased over the past three decades.

So, Professor Wake, what does the future hold for us?

It depends. Projections of future climate change depend fundamentally on how much greenhouse gas we put into the atmosphere through the burning of fossil fuels. Our climate future is truly in our hands. If we continue on a "business-as-usual" course and continue to rely primarily on fossil fuel for our source of energy, carbon dioxide levels will likely rise to around 1000 ppm by the end of this century—more than three times higher than the maximum level of carbon dioxide in the atmosphere over the past 420,000 years (*Figure 1*). If carbon dioxide reaches this level, there will be significant changes to our climate, including an increase in global temperatures from 5–10°F, and an increase in sea level rise from 1–3 feet by 2100 AD. These changes will affect every sector of our economy and our quality of life.

However, we do not have to follow “business-as-usual” into the future. We can improve the efficiency with which we generate and use energy—for example, building more energy efficient power generating stations and buildings, and producing more fuel-efficient cars. We can also produce more of our energy from renewable resources (wind, water, wood, solar). By doing so, we can map a path to a prosperous future while limiting the amount of greenhouse gases we produce and, thereby, reduce the amount of global warming.

Let’s use the Durham campus of UNH as an example. The University has completed a detailed greenhouse gas emissions inventory quantifying the amount of greenhouse gas emitted every year since 1990. In 2006, a new combined heat and power (CHP) plant was built on campus to generate electricity and to heat/cool university buildings. The efficiency of this CHP plant is about twice that of a basic electrical generating plant because the “waste” heat is captured and used on campus. When the CHP plant came online in the spring of 2006, our greenhouse gas emissions fell by about 20% below 1990 levels.

This is about three times below what was called for in the Kyoto Protocol, the international agreement that the United States chose not to ratify. Here is the kicker. The University will save \$30–\$40 million over the next 20 years because of the improved efficiency of the CHP plant. Our approach to the global warming problem can no longer be the economy verses the environment. The UNH and other examples show that good economic policy and good environmental policy go together.

Following a more sustainable energy pathway in the future actually solves four problems at once. First, increasing our production of homegrown renewable energy and using that energy more efficiently will reduce our reliance on foreign fossil fuel and thereby improve our energy security. Second, investing in energy efficiency and renewable technology can jump start a new, high-tech economy that will require well-trained workers and well-paying jobs that are good for our economy and the job market when you graduate. Third, reducing carbon dioxide emissions will also reduce emissions of a wide range of pollutants that will lead to improved public health. And finally, we will address the climate change issue.

However, the sustainable pathway will not happen without considerable effort to change the way this nation operates. One of the not-so-subtle ironies of climate change is that it is the baby boomers “gift” to your generation. The lifetime of carbon dioxide in the atmosphere is about 100 years. While we are beginning to experience the effects of human-induced climate change, the boomer generation will be long gone by the time

we experience more significant impacts of a changing climate. How our society deals with the climate change issue will be a defining characteristic of the 21st century. This is an issue your generation will debate at length and will need to deal with. And dealing with this issue in a meaningful way will require forward thinking and long-term planning that addresses both reducing greenhouse gas emissions and adapting to the climate changes that are already in the pipeline. This discussion is just the beginning.

Courses

ESCI 405, Global Environmental Change
 ESCI 409, Environmental Geology
 NR 415, Global Biological Change
 NR 435, Contemporary Conservation Issues
 ESCI 514, Introduction to Climate
 ESCI/NR 795/895, Earth System Science

Additional Resources - Books

IPCC, *Climate Change 2001: The Science of Climate Change*. Cambridge University Press. (www.ipcc.ch)

Markham, A. and C. Wake (2005) “Indicators of Climate Change in the Northeast - 2005.” Clean Air - Cool Planet, Portsmouth, NH. (<http://cleanair-coolplanet.org/>)

Philander, S.G. 1998. *Is the Temperature Rising? The Uncertain Science of Global Warming*. Princeton University Press, Princeton, NJ.

UNH Office of Sustainability 2004. UNH Greenhouse Gas Emissions Inventory (http://www.sustainableunh.unh.edu/climate_ed/greenhouse_gas_inventory.html)

Weart, S. 2004. *The Discovery of Global Warming*. Harvard University Press, Cambridge, MA. (www.aip.org/history/climate/)

Additional Resources - Film

An Inconvenient Truth (<http://www.climatecrisis.net/>)

References/Footnotes

Hansen et al. (1999) *Journal of Geophysical Research* 104, p. 30, 997. Data from <http://www.giss.nasa.gov/data/update/gistemp/>

Keeling, C.D. and T.P. Whorf. 2005. Atmospheric CO₂ records from sites in the SIO air sampling network. In Trends: A Compendium of Data on Global Change. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A (<http://cdiac.ornl.gov>)

Mann et al., 1999. Northern Hemisphere temperatures during the past millennium: Inferences, uncertainties, and limitations *Geophysical Research Letters* 26(6), p.759-762.

Petit J.R. et al. 1999. Climate and atmospheric history of the past 420,000 years from the Vostok ice core, Antarctica. *Nature* 399, p. 429-436.

Figure 1. The graph represents carbon dioxide measurements from the summit of Mauna Loa in Hawaii. The red line represents monthly averages and the blue line represents annual averages. The measurements were made from air drawn in from the top of the tower on the left hand side of the photograph. Data from Keeling and Whorf (2005).

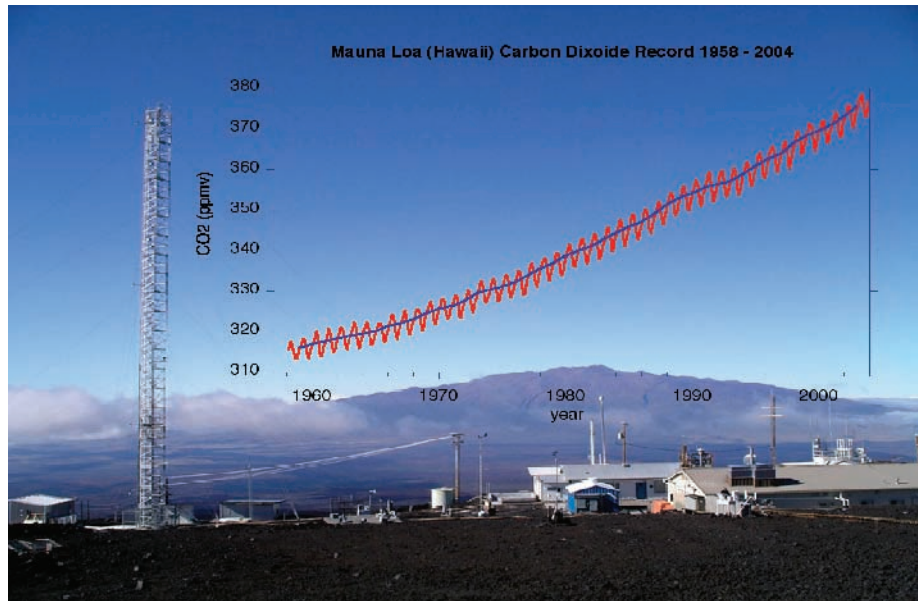
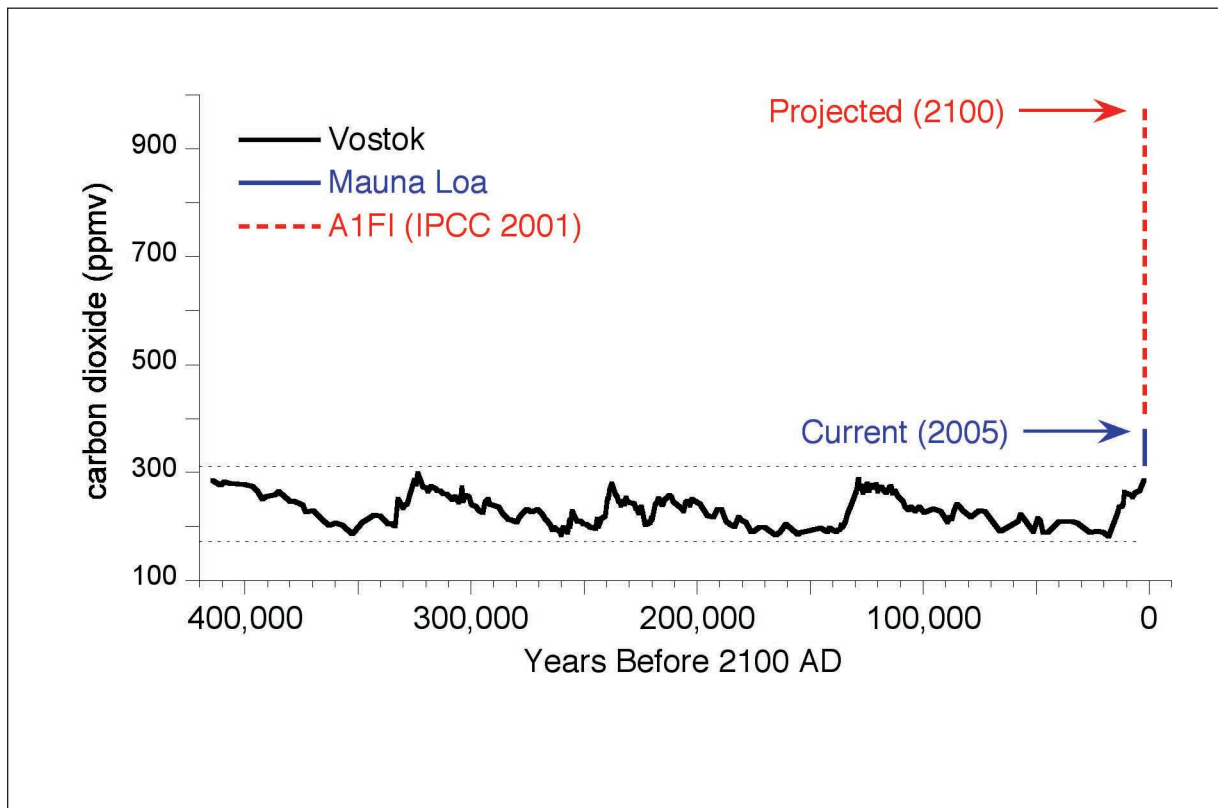


FIGURE 1

Figure 2. Atmospheric carbon dioxide, past, present, and future in parts-per-million by volume (ppmv). The black line represents the 420,000-year record of carbon dioxide measured in air bubbles in an ice core recovered from the Vostok, Antarctica. The blue line represents the Mauna Loa, Hawaii record from 1957 to 2005 (also shown in more detail in Figure 1). The red line represents predicted future carbon dioxide levels in

the atmosphere if we continue to rely primarily on fossil fuels for our energy production (based on the IPCC A1 - Fossil Intensive Scenario). Data from Petit et al., (1999), Keeling and Whorf (2005), and IPCC (2001).

FIGURE 2



Departures in temperature in °C (from the 1990 value)

Figure 3. Temperature change over the last 1,000 years in the northern hemisphere as documented by a combination of tree-ring, ice core, coral, and instrumental records, combined with projected temperature change in the future under different greenhouse gas emission scenarios. The red line represents the decadal trends in temperature over the last 100 years, while the grey area around the red line represents the uncertainty in the record. Note that the recent few decades have been the warmest of the last 1000 years and that projected global temperatures will be much higher than we have experienced in the past 1000 years. Data from Mann et al. (1999) and IPCC (2001).

FIGURE 3

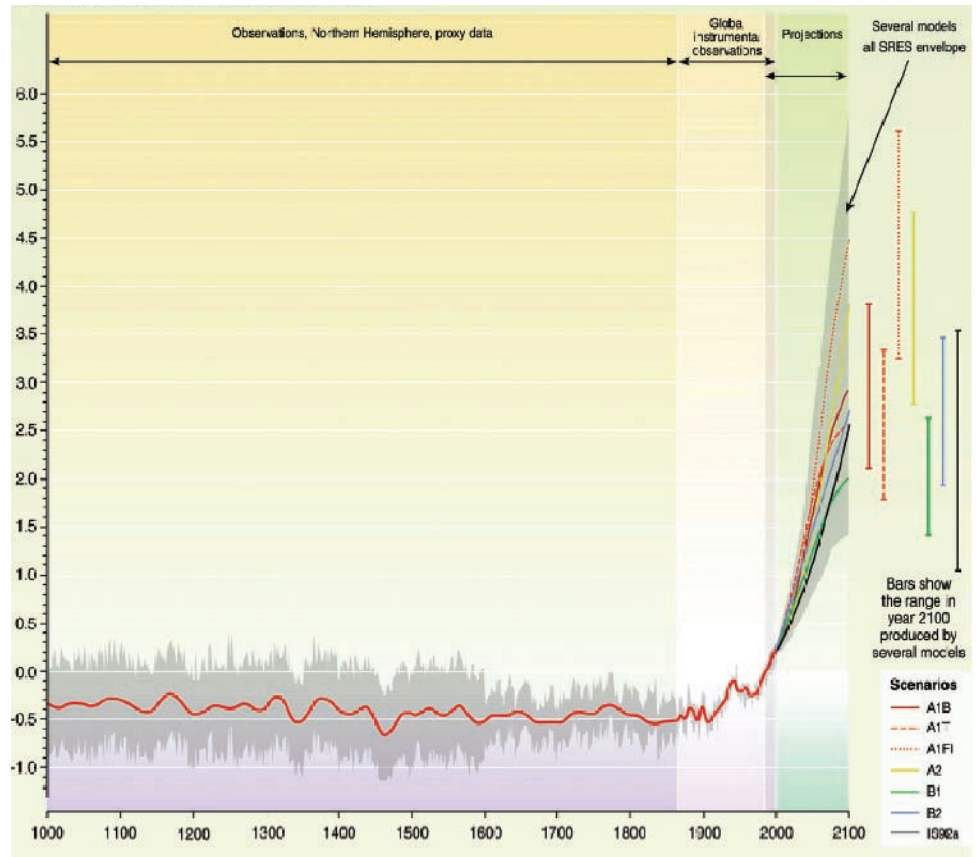


FIGURE 4

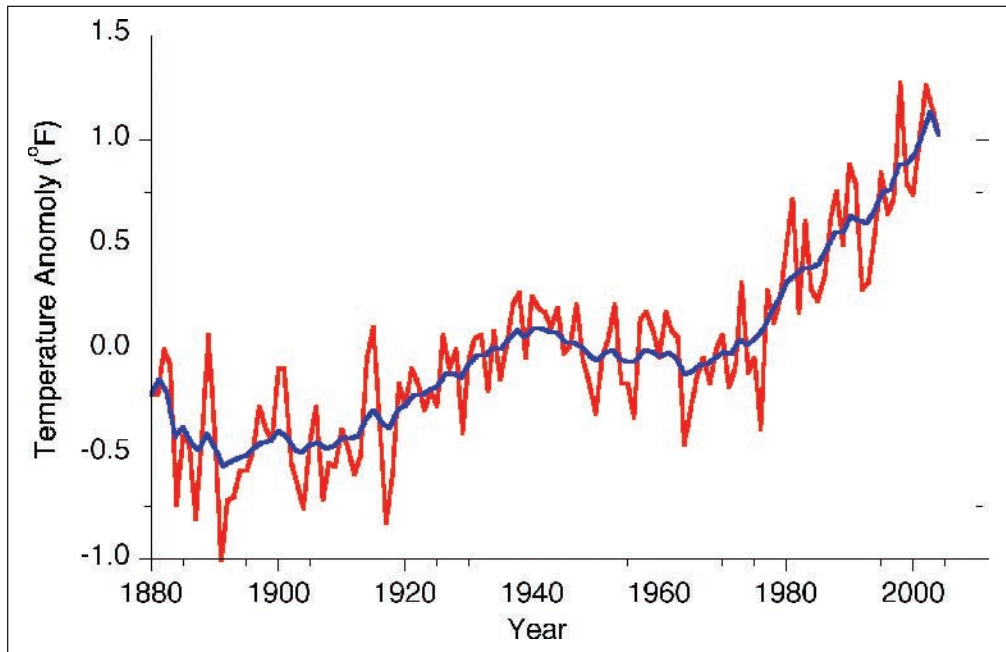


Figure 4. Annual global average temperatures from meteorological station data. The red line represents annual data and the blue line a 5 year running average. Data from Hansen et al. (1999).