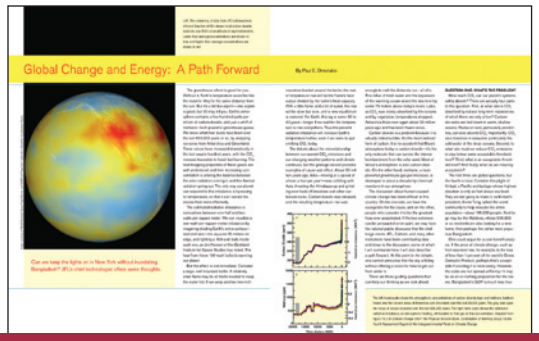

Global Change and Energy: A Path Forward

LETTERS

Last issue's "Global Change and Energy: A Path Forward" by Paul Dimotakis (BS '68, MS '69, PhD '73) drew quite a number of comments, including at least one in the blogosphere ("Critical Section" by Ole Eichhorn, BS '79), http://www.w-uh.com/posts/090115a.html:

"Want to learn about global warming? Really? Then check out *Global Change and Energy: A Path Forward* (PDF) by Paul Dimotakis in Caltech's *Engineering & Science* magazine. He sets politics and sensationalism aside and honestly examines global warming from a scientific standpoint. This is the best analysis I've read, by someone who really understands the underlying science. (The punch line: global warming is real, it is exacerbated by human activity, and it isn't as bad as Al Gore thinks.)"

Not everyone applauded. Peter Metcalf (BS '62) called it "junk science at its worst," saying:

"We know the British climate was warmer in Roman times, and in the times of the Norman Conquest than it is today. Although the CO_2 concentration in the atmosphere has increased a bit in recent times, and the temperature is currently going up a bit, there is little evidence that increasing CO_2 concentrations has a significant effect on the earth's temperature compared with, say changes in solar radiation. . . . Specific errors in the Dimotakis article include, but are not limited to, the following:

"▪ The phrase 'the CO_2 increase [is] traceable to fossil-fuel burning' is followed immediately by the counter example of thrusting tectonic plates.

"▪ The main greenhouse gas—water vapor—is not mentioned at all.

"▪ The article included a material balance showing that [CO_2] generation from fossil fuels—6.3 gigatons (gt)—is absolutely trivial compared with total CO_2 generation (209 gt). And the material balance cited does not include 'thrusting tectonic plates' or volcanoes which are probably the biggest sources of CO_2. As a chemical engineer with many years of experience in carrying out material balances, I cannot image attributing changes in the CO_2 concentration to such a small source of CO_2 as the burning of fossil fuel."

Many readers proffered their own paths forward, usually by endorsing solar or nuclear power.

Some were more visionary: Roy Britten, an emeritus senior research associate in biology, proposed fleets of millions of floating wind turbines to be distributed over hundreds of thousands of square kilometers and anchored to mid-ocean seamounts to harvest the steady energy of the trade winds.

Olivier Roy (MS '80) went even farther: "If a fraction (1% or maybe even less?) of the solar energy reaching the earth could be reflected on top of what the earth already reflects, the global energy balance between Earth and space would be slightly modified so that more energy leaves the earth than is captured. Say a satellite is sent to space and when in orbit, it expels particles . . . made of a light, highly reflective material like Kevlar. . . . The confetti would not be too much of a disturbance for people looking up in the sky if the cloud [was] loose enough, [and] the potential interference with geostationary satellites could be avoided if the orbit is at a higher altitude."

"This is the best analysis I've read, by someone who really understands the underlying science. (The punch line: global warming is real, it is exacerbated by human activity, and it isn't as bad as Al Gore thinks.)"

Professor Dimotakis replies:

Dear Editor,

Thank you to all the readers of *E&S* for their gracious notes and thoughtful discussion. I would like to reply to a few specifically here.

Roy Britten suggests that mid-ocean wind turbines be used to electrolyze water to produce hydrogen that is then compressed and shipped to shore. From a thermodynamic standpoint, it would be preferable to produce work directly from the electricity, which can be done with high conversion efficiency. Hydrogen must be burned to produce work, with a much lower conversion efficiency. One can do better with fuel cells, but there's still an overall loss.

Olivier Roy proposes space-borne reflectors to help cool the planet. Other similar proposals have been put forth. Their main difficulty is the great expense of lofting the requisite mass,

even to low-Earth orbit. However, if we fail to trim our carbon emissions, such ideas, generically referred to as geoengineering, may prove necessary.

Peter Metcalf noted that man-made carbon sources are a small contributor to the carbon cycle. He and others also noted that water vapor was not mentioned at all. Water vapor is, indeed, the most important greenhouse gas. However, its concentration is dictated by temperature; the atmosphere has access to plenty of water. Increase the temperature and water vapor content increases, and conversely. As a result, water vapor *amplifies* the greenhouse effect, but does not cause it.

Earth is a dynamic, chaotic system capable of large excursions—both ice ages and warming periods—without help from humans. The climate record indicates, however, that we are presently already experiencing warming outside that of human experience, with more anticipated even without adding to the human-emitted carbon that has already led to extraordinary atmospheric concentrations of CO_2. (See the figure at right.) Predicted temperature increases from this buildup—ranging from analyses done a century ago to those based on present-day computer models—correlate well with the rising concentrations of greenhouse gases from fossil-fuel burning. Such increases are above and beyond whatever nature doles out.

* * *

I would also like to acknowledge some more of the many people who contributed supporting material to the article, and correct or amplify a couple of points:

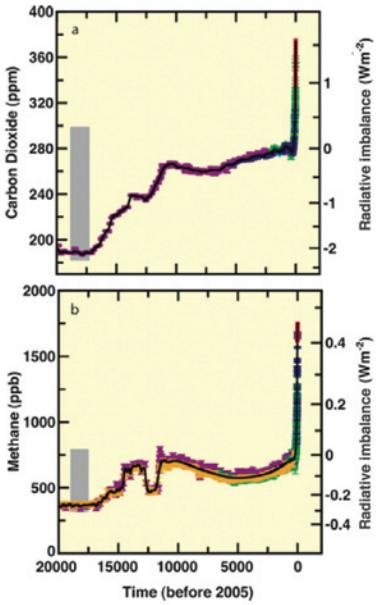
The Orbiting Carbon Observatory (OCO)'s principal investigator is David Crisp of JPL. OCO would have significantly reduced uncertainties in carbon sources and sinks on Earth's surface, providing important data on the carbon cycle. Unfortunately, OCO's launch on February 24, 2009, was unsuccessful. Indications are that the fairing on the Taurus XL launch vehicle failed to separate. A reflight is under consideration at this writing.

The Microwave Limb Sounder (MLS)'s principal investigator is Nathaniel Livesey, also of JPL. MLS measures the amount of atmospheric water vapor from about 9 kilometers up to about 80 kilometers. The Atmospheric Infra-Red Sounder (AIRS) measures water vapor from the surface up to about 11 kilometers. In combination, they measure water vapor from Earth's surface to the edge of space. When correlated with sea-surface temperatures estimated by other means (MLS does not measure sea-surface temperature), MLS and AIRS observations show an increase of cirrus clouds and water vapor over warm oceans, indicating that cloud and water-vapor feedbacks amplify global warming. Sources of sea-surface temperature data include the National Weather Service and AMSR-E instrument measurements on NASA's Aqua satellite. My thanks to Jonathan Jiang and Hui Su of JPL's Microwave Atmospheric Science Team for this.

CloudSat is operated by NASA/JPL and Colorado State University. The principal investigator is Graeme Stephens of Colorado State.

And finally, the results derived from the JPL-UCLA collaboration on water and the snow pack on the Sierras were based on model runs executed for the IPCC 2007 report. This analysis was performed by Duane Waliser of JPL.

Thank you again,
Paul Dimotakis



The left-hand scale shows the atmospheric concentrations of carbon dioxide (top) and methane (bottom) frozen into the ice and snow of Antarctica and Greenland over the last 20,000 years. The gray bars span the range of values recorded over the last 650,000 years. The right-hand scale shows the estimated radiative imbalance, or atmospheric heating, attributable to that gas at that concentration. Adapted from figure TS.2 of *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.*