

# THE DECADE AFTER TOMORROW

## Modeling Global Climate Change at Berkeley

by Kristen DeAngelis

FROM CAMPUS, THE GENTLE SLOPE OF THE BERKELEY HILLS affords views of sunsets painted in electric oranges and psychedelic reds. But the spectacular nightly show owes more to light reflecting off greenhouse gases and pollutants than to Nature herself. While observations like this might crush the mood of an evening stroll, they fuel research at the UC Berkeley Atmospheric Sciences Center (or BASC), whose stated goal is to understand the nature of global climate change and discern the true magnitude of human impact upon it. One of the most important aspects of BASC's research is the construction of global climate change scenarios to reflect the likely consequences of human actions.





A familiar view of the San Francisco Bay.

Making projections about how current scenarios of carbon emissions will affect global climate is a nuanced science, combining computing technology with a certain amount of subjective interpretation. Achieving an appropriate balance between the two is the work of Inez Fung, professor in the Department of Earth and Planetary Science and Environmental Science, Policy, and Management, as well as the director of BASC. Fung constructs computer models of global climate change: “huge, monster climate models, [incorporating] the atmosphere, the land, the ocean, the ice.” Such models may allow scientists to better understand what controls the release and breakdown of greenhouse gases like CO<sub>2</sub>.

## Model Behavior

THE first ingredient in Fung's computer model is hard climate data, such as CO<sub>2</sub> levels. Many of these data are now being supplied by the FLUXNET system of data collection towers. FLUXNET is a NASA-sponsored project combining the efforts of several existing regional networks from Europe, Asia, Australia, New Zealand, Korea, Thailand, Canada, and the Americas into a global network. FLUXNET consists of over 200 eddy flux towers, or climate data collection systems, that continuously measure changes in the concentration of CO<sub>2</sub>, as well as other variables like water vapor, light, and heat energy. These flux towers have yet to completely replace traditional data collection networks, such as manned research stations, which collect hourly observations of CO<sub>2</sub>, wind, temperature and other climate vital signs. Another old-fashioned source of climate data is the "flask network," a direct collection of atmospheric gases taken by "holding up an evacuated flask, holding your breath, and opening the valve to the air," describes Fung. Pooled data from all of these sources allow Fung to evaluate climate on a global scale. "They don't let me into the field," she says blithely about the actual data collection. "It's a community effort; I'm basically a black hole for all the data."

Once the data has been funneled into Fung's inbox, the next challenge is to incorporate information from thousands of distinct collection sites into a unified, global model. According to Abby Swann, a graduate student in Fung's lab, part of the power of FLUXNET is that it generates data that can "be realized as a network dataset and not as a bunch of individual sites." In

order to incorporate all these data into scenarios that are relevant on a global scale, massive models must be generated—each consisting of thousands of lines of code and requiring months to run.

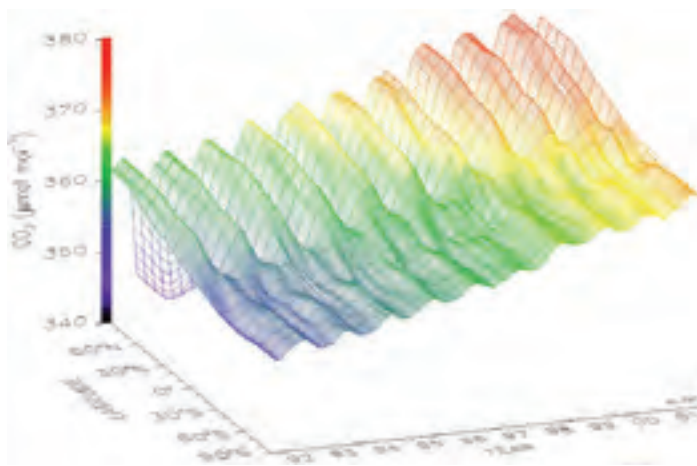
Although atmospheric field observations are a vital component of Fung's gigantic computer models, they are not the whole story. These extensive measurements merely present a snapshot of global climate conditions at a particular point in time; from this starting dataset, the climate models then generate predictions of how climate conditions will change. In order to make such predictions, Fung must figure out which variables (such as automobile emissions or photosynthesis) have an impact on global atmospheric conditions, then quantify what their impact will be. To achieve this, Fung's models reduce all living things into basic functional groups. "From my perspective, I don't care who you are; it's what you do that counts." Latin names don't matter in Fung's model universe. Instead, everything is reduced to a respirer or a photosynthesizer, an herbaceous or woody plant, a methane producer or methane eater, and so on.

These functional groups comprise a series of inputs and outputs of carbon in the atmosphere, called sources and sinks, respectively. Sources are just that: sources of CO<sub>2</sub> released into the atmosphere. A minor source is your own respiration as you convert your lunch into energy and CO<sub>2</sub> by-product, while a major source is a coal-burning power plant that supplies many communities with power. Sinks, on the other hand, convert CO<sub>2</sub> into biomass; the largest global sink is photosynthesis, carried

out by plants and algae. Fung's models base their climate projections in part on how much CO<sub>2</sub> each source or sink contributes or removes from the atmosphere.

Complicating models of CO<sub>2</sub> cycling is the fact that the amount of carbon dioxide processed by each

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Three-dimensional representation of the latitudinal distribution of atmospheric carbon dioxide in the marine boundary layer for the period 1992 through 2001. Data is from the NOAA CMDL cooperative air sampling network.

source or sink can be difficult to quantify. A plant's ability to act as a carbon sink, for instance, is partly dependent on the surrounding temperature. Plant leaves are riddled with tiny holes called stomates, which the plant opens to permit CO<sub>2</sub> intake for photosynthesis and closes to prevent water loss. At high temperatures, a plant closes its stomates to prevent dehydration; this simultaneously prevents the absorption of CO<sub>2</sub> and limits the plant's ability to act as an atmospheric sink. Thus, climate models attempting to account for global CO<sub>2</sub> flux cannot simply estimate the number of plants available to perform photosynthesis. They must also incorporate calculations of how temperature and a host of other factors affect the efficiency of plants' CO<sub>2</sub> uptake. A dizzyingly large number of variables can be required to calculate the global impact of even a single sink, like photosynthesis.

Another hurdle to global climate modeling is accounting for differences in CO<sub>2</sub> processing between various ecosystems. A relatively dry, unproductive desert, for example, might not respond to variations in CO<sub>2</sub> or the resulting changes in soil water availability in the same way as a more fertile environment, like a forest. This is simply a result of the number of plants capable of responding to CO<sub>2</sub> variations. Furthermore, different ecosystems do not exist in isolation; they are intimately connected to the atmosphere and climate. "The drought that the US saw for the last several years has decreased photosynthesis—we see decreases in the

satellite greenness index [and] we see the influence of decreased photosynthesis in the US in the CO<sub>2</sub> data at Hawaii," Fung points out. And when she enters recent temperature and precipitation patterns into her ecosystem models, she finds that "we actually can predict—or hindcast—the decrease in productivity. So, all of that is tied together." Climate researchers must therefore account for complex interconnectivity between distinct environments in their computer models.

## Reality Check

Despite their sophistication, Fung insists that her models do not predict the future; a prediction implies that something will happen. Rather, they project how different scenarios of human behavior *might* affect greenhouse gas levels, and how these gas levels in turn might affect global climate change. The generated projection is only a mathematical estimate of future conditions based on current data and trends. In her words, "They're not predictions, they're not simulations. They're basically an articulation of the communal knowledge."

So far, the model's projections look accurate—the computer's predictions agree well with real-world observations. For example, the 1991 eruption of Mount Pinatubo in the Philippines was a massive disturbance that allowed Fung to test whether the models could predict the consequences of such a large disturbance as well as natural year-to-year climate changes. She provided the computer model with atmospheric data from immediately before and after the eruption, then asked it to predict how the volcano would impact ecosystem functioning and atmospheric CO<sub>2</sub>. Actual satellite and ground-based data collected after Pinatubo's eruption revealed a reduction in photosynthesis, causing fluctuations of CO<sub>2</sub>. The output of Fung's ecosystem models match these observations: "The fact that we can reproduce the photosynthetic response to changes in temperature, precipitation and solar energy reaching the surface gives us confidence that we have a handle on how plants respond to climate perturbations."

In addition to the natural parameters of the atmospheric cycle, as defined by Fung and programmed into the

computer model, researchers can also specify human behaviors, such as gross CO<sub>2</sub> emissions. In one scenario, CO<sub>2</sub> emissions continue to rise, triggering temperature rises and causing dramatic climatic changes on a time scale of decades. In another scenario, human emissions are curbed and the global changes are less dramatic. However, all outcomes are accompanied by a certain amount of statistical uncertainty. “It is not an option to report findings without [statistical uncertainties], for they would not be acceptable in the scientific community, and therefore won’t be trusted by the general public either,” according to Swann. But convincing people of “uncertain” results is a tough sell.

One scenario in particular has resulted in some dangerous misconceptions. Plants’ ability to generate tissue from CO<sub>2</sub>, water, and light forms the basis of the food chain, as well an important sink for atmospheric CO<sub>2</sub>. Small-scale studies have indicated that certain plants increase in biomass with increasing CO<sub>2</sub> levels. This tempts some to speculate that rising levels of CO<sub>2</sub> in the atmosphere might trigger an increase in plant biomass and buffer potential greenhouse problems. Fung and her colleagues have examined just such interactions between climate and vegetation with less optimistic results. Given a doubling of atmospheric CO<sub>2</sub>, their models showed slight increases of photosynthesis in some tropical regions. In northern latitudes however, the photosynthesis decreased as a result of high temperature stress on the plants. Altogether the model predicted no net change in global mean photosynthesis and a net increase in atmospheric temperature.

### Getting the Word Out

Fung intends to provide outcome scenarios for the coming decades based upon potential emissions

decisions that face us today. “I can’t write an equation for human behavior,” she points out, so instead she approximates land cover changes that might occur due to urbanization, deforestation, or conversion of wild lands to industrial agriculture. She then feeds these estimates into her computer models to project a range of potential environmental outcomes. These human impact projections will hopefully guide policy decisions on CO<sub>2</sub> emissions.

In May of 2003 the Bush administration requested such guidance from the National Academy of Science. What was unusual about the request was that the group was given only two weeks to analyze the current state of global climate change research and recommend “maximum acceptable levels of greenhouse gases.” The scope and rapid completion of the report reflect the deep dedication of Fung and her co-authors, among them Ralph Cicero, Chancellor of the University of California at Irvine, and Sherwood Rowland, who received a Nobel Prize in Chemistry for his work on the ozone hole.

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The central finding of the report is aptly summarized by the first sentence: “Greenhouse gases are accumulating in Earth’s atmosphere as a result of human activities, causing surface air temperatures and sub-surface ocean temperatures to rise.”

The report concisely cites numerous data showing rising CO<sub>2</sub> emissions, methane emissions, and damage to the stratospheric ozone layer. All

of this supports an accelerating trend of global climate change. Although climate change scenarios presented by the movie *The Day After Tomorrow* are unrealistic in their abruptness and scale, gradual increases in sea level, abruptly changing weather patterns, and rising temperatures are legitimate possibilities. Fung points out that “the sea level rise is not going to be a tsunami hitting Manhattan, it will be the people in Bangladesh, the people who live in Maldives, on the South Pacific

islands [losing their homes]. The movie of course is an exaggeration; even rapid climate change is not going to occur overnight. It will be on a decadal time scale, so on a timescale of government, you can [still] do something about this.”

In the interests of addressing this responsibility, the administration who commissioned the report particularly wanted to determine a maximum acceptable level of greenhouse gas. According to Fung, this is not enough—global climate change is real, and infrastructure and cultural changes must be implemented now in order to head off potentially disastrous scenarios in the decades to come.

The report was received with immediate recognition from the administration, and in fact was addressed by President Bush in his Rose Garden speech in June of 2003. This delighted Fung, who did not seem to expect such immediate recognition for her work. Indeed, in the executive summary of the White House Global Climate Change Policy Book, President Bush says, “Addressing global climate change will require a sustained effort, over many generations.” The stated Bush Administration policy includes a pledge to reduce “Greenhouse Gas Intensity” by 18% through voluntary measures in the next ten years. This measure is a ratio of greenhouse gas emissions relative to the Gross Domestic Product.

However, as GDP rises, total greenhouse emissions will still increase by 12% under this plan. Thus, Fung suggests that Bush’s plan “is not the right approach. The source of the problem is the emissions,” and these will continue to rise. Additionally, because all reporting of greenhouse gas emissions is voluntary under the current policy, there is no independent verification of the data that industry reports to the government. Policy decisions aside, the bottom line is that global climate change can be



The FLUXNET system of climate data collection stations incorporates over 15 previously existing regional collection networks into one global network. Researchers have access to information from over 200 stations worldwide.

understood, and even controlled, because of dedicated scientists like Fung and her colleagues. The projections are not firm predictions. We are not locked into any particular global warming outcome—at least not yet. Further collaboration between BASC and global climate monitoring system FLUXNET will allow the scientific community to illuminate the realities of climate change for the American government and the global public, hopefully enabling responsible policy decisions in the decades to come.

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#### Want to know more?

To keep abreast of research in the Berkeley Atmospheric Sciences Center labs, see [www.atmos.berkeley.edu](http://www.atmos.berkeley.edu)

Visit the National Academy of Sciences website for the full text of the report entitled “Climate Change Science: An Analysis of Some Key Questions.” [books.nap.edu/catalog/10139.html](http://books.nap.edu/catalog/10139.html)

## The Warm California Sun

IMAGINE two futures for California, decades from now: One in which global CO<sub>2</sub> emissions have continued unchecked, the other in which emissions have been curbed. How closely would they resemble the state we live in today? In a study published in the August issue of *Proceedings of the National Academy of the Sciences*, a team including Katherine Hayhoe of ATMOS research and consulting, UC Berkeley researcher Michael Hanemann, and LBL scientists Larry Dale and Norman Miller has attempted to answer this question with a ‘California-specific’ climate change study. The researchers use two downscaled global climate models to examine the range of “climate futures” resulting from hypothetical scenarios of low and high CO<sub>2</sub> emissions in the years to come. The high-emissions scenario posits no reductions in global CO<sub>2</sub> emissions; the low-emissions scenario posits a general reduction, without specifying a particular reduction policy. The study projects climate anomalies and impacts for the years 2020-2049 and 2070-2099. Among the scientists’ conclusions:

- Even in the low-emissions scenario, summer temperatures in California rise 4-8°F by the end of the century. Worse yet, “if nothing is done to curb our use of fossil fuels, summer temperatures rise a dramatic 7.5-15°F,” Hanemann says. Projected heat-related deaths in Los Angeles increase two- to threefold with lowered emissions, five- to sevenfold with unchecked emissions.
- Winter temperatures rise less than summer, but even so, under the high-emissions scenario California loses 70-90 percent of the Sierra Nevada snowpack by the end of the century. “Skiing with natural snow in the Sierras would vanish, except possibly at the very highest elevations,” Hanemann cautions.
- California’s water supply will suffer due to the reduction of snowpack and the increased summer heat. The study projects increases of 50-64 percent in the proportion of drought years.

The take-home messages? Hanemann points to two: that California will experience significant adverse effects of greenhouse gas emissions within the next 30 years, and that because of time lags in the global climate systems, consequences after about 2050 will be significantly more harmful if no action is taken now. —*Jess Porter*

## Quantum

[heard on campus]

“The [telescope] feeds are dual linear polarization, and SETI will add dual circular polarization, since as we all know aliens transmit circularly.”

Dave DeBoer (SETI Institute & UCB Radio Astronomy Lab), “Splitting the Aperture: The Allen Telescope Array”, responding to a question about their polarization sensitivity.

## Webwatch

### [sciencematters.berkeley.edu](http://sciencematters.berkeley.edu)

Can’t get enough of Berkeley science? Check out the College of Letters and Sciences’ new monthly electronic newsletter “*Science Matters*”.

### [www.evolution.berkeley.edu](http://www.evolution.berkeley.edu)

Do you believe in evolution? According to this website, the correct answer is “No, I accept the fact that the Earth is very old and life has changed over billions of years because that is what the evidence tells us.” Science is not about belief—it is about making inferences based on evidence.

### [www.LTERnet.edu](http://www.LTERnet.edu)

Established in 1980 by the National Science Foundation, the Long Term Ecological Research (LTER) Network includes over 2000 ecological datasets. It is part of a network-wide information system designed to facilitate data exchange and integration to meet the needs of ecological scientists.

### <http://quake.usgs.gov/recenteqs/latest.htm>

“Did you feel that?” See the location and magnitude of earthquakes occurring in California and Nevada in the last week, day, and hour.